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附錄一 非正交水深平均控制方程式

(Non-Orthogonal Depth-Averaged Governing Equations)

水流連續方程式：

$$\frac{\partial h}{\partial t}+g_{11}^{-0.5}g_{22}^{-0.5}\frac{\partial\left[g_{22}^{0.5}\cdot\bar{u}h\right]}{\partial\xi}+g_{11}^{-0.5}g_{22}^{-0.5}\frac{\partial\left[g_{11}^{0.5}\cdot\bar{v}h\right]}{\partial\eta}$$
$$+\frac{1}{2}g_{11}^{-0.5}\left(g^{11}\frac{\partial g_{11}}{\partial\xi}+2g^{12}\frac{\partial g_{12}}{\partial\xi}+g^{22}\frac{\partial g_{22}}{\partial\xi}-g_{22}^{-1}\frac{\partial g_{22}}{\partial\xi}-g_{11}^{-1}\frac{\partial g_{11}}{\partial\xi}\right)\cdot\bar{u}h$$
$$+\frac{1}{2}g_{22}^{-0.5}\left(g^{11}\frac{\partial g_{11}}{\partial\eta}+2g^{12}\frac{\partial g_{12}}{\partial\eta}+g^{22}\frac{\partial g_{22}}{\partial\eta}-g_{11}^{-1}\frac{\partial g_{11}}{\partial\eta}-g_{22}^{-1}\frac{\partial g_{22}}{\partial\eta}\right)\cdot\bar{v}h$$
$$=0$$

ξ 方向水流動量方程式：

$$\frac{\partial\bar{u}}{\partial t}+g_{11}^{-0.5}\cdot\bar{u}\frac{\partial\bar{u}}{\partial\xi}+g_{22}^{-0.5}\cdot\bar{v}\frac{\partial\bar{u}}{\partial\eta}$$
$$+\frac{1}{2}g_{11}^{-0.5}(g^{11}\frac{\partial g_{11}}{\partial\xi}+2g^{12}\frac{\partial g_{12}}{\partial\xi}-g^{12}\frac{\partial g_{11}}{\partial\eta}-g_{11}^{-1}\frac{\partial g_{11}}{\partial\xi})\cdot[\bar{u}^{2}]$$
$$+\frac{1}{2}g_{22}^{-0.5}(g^{11}\frac{\partial g_{11}}{\partial\eta}+g^{12}\frac{\partial g_{22}}{\partial\xi}-g_{11}^{-1}\frac{\partial g_{11}}{\partial\eta})\cdot[\bar{\bar{u}\bar{v}}]$$
$$+\frac{1}{2}g_{22}^{-0.5}(g^{11}\frac{\partial g_{11}}{\partial\eta}+g^{12}\frac{\partial g_{22}}{\partial\xi})\cdot[\bar{\bar{u}\bar{v}}]$$
$$+\frac{1}{2}g_{11}^{0.5}g_{22}^{-1}(2g^{11}\frac{\partial g_{12}}{\partial\eta}-g^{11}\frac{\partial g_{22}}{\partial\xi}+g^{12}\frac{\partial g_{22}}{\partial\eta})\cdot[\bar{v}^{2}]$$
$$+\frac{1}{d}g_{11}^{-0.5}g_{22}^{-0.5}\frac{\partial}{\partial\xi}[g_{22}^{0.5}\frac{1}{N(N+2)}\bar{u}^{2}h]+\frac{1}{d}g_{11}^{-0.5}g_{22}^{-0.5}\frac{\partial}{\partial\eta}[g_{11}^{0.5}\frac{1}{N(N+2)}\bar{\bar{u}\bar{v}}h]$$
$$+\frac{1}{2}g_{11}^{-0.5}(g^{11}\frac{\partial g_{11}}{\partial\xi}+2g^{12}\frac{\partial g_{12}}{\partial\xi}-g^{12}\frac{\partial g_{11}}{\partial\eta}-g_{11}^{-1}\frac{\partial g_{11}}{\partial\xi})\cdot[\frac{1}{N(N+2)}\bar{u}^{2}]$$
$$+\frac{1}{2}g_{22}^{-0.5}(g^{11}\frac{\partial g_{11}}{\partial\eta}+g^{12}\frac{\partial g_{22}}{\partial\xi}-g_{11}^{-1}\frac{\partial g_{11}}{\partial\eta})\cdot[\frac{1}{N(N+2)}\bar{\bar{u}\bar{v}}]$$
$$+\frac{1}{2}g_{22}^{-0.5}(g^{11}\frac{\partial g_{11}}{\partial\eta}+g^{12}\frac{\partial g_{22}}{\partial\xi})\cdot[\frac{1}{N(N+2)}\bar{\bar{u}\bar{v}}]$$
$$+\frac{1}{2}g_{11}^{0.5}g_{22}^{-1}(2g^{11}\frac{\partial g_{12}}{\partial\eta}-g^{11}\frac{\partial g_{22}}{\partial\xi}+g^{12}\frac{\partial g_{22}}{\partial\eta})\cdot[\frac{1}{N(N+2)}\bar{v}^{2}]$$
$$+\frac{1}{2}g_{11}^{-0.5}(g^{11}\frac{\partial g_{11}}{\partial\xi}+2g^{12}\frac{\partial g_{12}}{\partial\xi}+g^{22}\frac{\partial g_{22}}{\partial\xi}-g_{22}^{-1}\frac{\partial g_{22}}{\partial\xi}-g_{11}^{-1}\frac{\partial g_{11}}{\partial\xi})\cdot[\frac{1}{N(N+2)}\bar{u}^{2}]$$
$$+\frac{1}{2}g_{22}^{-0.5}(g^{11}\frac{\partial g_{11}}{\partial\eta}+2g^{12}\frac{\partial g_{12}}{\partial\eta}-g_{11}^{-1}\frac{\partial g_{11}}{\partial\eta}+g^{22}\frac{\partial g_{22}}{\partial\eta}-g_{22}^{-1}\frac{\partial g_{22}}{\partial\eta})\cdot[\frac{1}{N(N+2)}\bar{\bar{u}\bar{v}}]$$

$$+\frac{1}{h}g_{11}^{-0.5}\frac{\partial}{\partial\xi}[\int_{z_b}^{z_s}\widetilde{\widetilde{u'^2}}\,dz]+\frac{1}{h}g_{22}^{-0.5}\frac{\partial}{\partial\eta}[\int_{z_b}^{z_s}\widetilde{\widetilde{u'v'}}\,dz]$$

$$+\frac{1}{2h}g_{11}^{-0.5}[2g^{11}\frac{\partial g_{11}}{\partial\xi}+4g^{12}\frac{\partial g_{12}}{\partial\xi}-g^{12}\frac{\partial g_{11}}{\partial\eta}+g^{22}\frac{\partial g_{22}}{\partial\xi}-2g_{11}^{-1}\frac{\partial g_{11}}{\partial\xi}]\int_{z_b}^{z_s}\widetilde{\widetilde{u'^2}}\,dz$$

$$+\frac{1}{2h}g_{22}^{-0.5}[3g^{11}\frac{\partial g_{11}}{\partial\eta}+2g^{12}\frac{\partial g_{22}}{\partial\xi}-g_{11}^{-1}\frac{\partial g_{11}}{\partial\eta}-g_{22}^{-1}\frac{\partial g_{22}}{\partial\eta}+2g^{12}\frac{\partial g_{12}}{\partial\eta}+g^{22}\frac{\partial g_{22}}{\partial\eta}]\int_{z_b}^{z_s}\widetilde{\widetilde{u'v'}}\,dz$$

$$+\frac{1}{2h}g_{11}^{0.5}g_{22}^{-1}[2g^{11}\frac{\partial g_{12}}{\partial\eta}-g^{11}\frac{\partial g_{22}}{\partial\xi}+g^{12}\frac{\partial g_{22}}{\partial\eta}]\int_{z_b}^{z_s}\widetilde{\widetilde{v'^2}}\,dz$$

$$=-g\cdot g_{11}^{0.5}g^{11}\frac{\partial(z_b+h)}{\partial\xi}-g\cdot g_{11}^{0.5}g^{12}\frac{\partial(z_b+h)}{\partial\eta}$$

$$+\frac{\nu}{h}\cdot\{$$

$$g^{11}\frac{\partial}{\partial\xi}[\int_{z_b}^{z_s}\frac{\partial u}{\partial\xi}dz]-g^{11}[\frac{\partial u_s}{\partial\xi}\frac{\partial z_s}{\partial\xi}]+2g^{12}\frac{\partial}{\partial\xi}[\int_{z_b}^{z_s}\frac{\partial u}{\partial\eta}dz]$$

$$-2g^{12}[\frac{\partial u_s}{\partial\eta}\frac{\partial z_s}{\partial\xi}]+g^{22}\frac{\partial}{\partial\eta}[\int_{z_b}^{z_s}\frac{\partial u}{\partial\eta}dz]-g^{22}[\frac{\partial u_s}{\partial\eta}\frac{\partial z_s}{\partial\eta}]+\frac{\partial u_s}{\partial z}-\frac{\partial u_b}{\partial z}$$

$$+[\frac{1}{2}(g^{11})^2\frac{\partial g_{11}}{\partial\xi}+g^{11}g^{12}\frac{\partial g_{12}}{\partial\xi}-\frac{1}{2}g^{11}g^{12}\frac{\partial g_{11}}{\partial\eta}-g^{11}g^{22}\frac{\partial g_{12}}{\partial\eta}$$

$$+\frac{1}{2}g^{11}g^{22}\frac{\partial g_{22}}{\partial\xi}-\frac{1}{2}g^{12}g^{22}\frac{\partial g_{22}}{\partial\eta}-g_{11}^{-1}g^{11}\frac{\partial g_{11}}{\partial\xi}-g_{11}^{-1}g^{12}\frac{\partial g_{11}}{\partial\eta}]\cdot[\int_{z_b}^{z_s}\frac{\partial u}{\partial\xi}dz]$$

$$+[\frac{1}{2}g^{11}g^{12}\frac{\partial g_{11}}{\partial\xi}-g^{11}g^{22}\frac{\partial g_{12}}{\partial\xi}+\frac{3}{2}g^{11}g^{22}\frac{\partial g_{11}}{\partial\eta}-2(g^{12})^2\frac{\partial g_{11}}{\partial\eta}-g^{12}g^{22}\frac{\partial g_{12}}{\partial\eta}+\frac{1}{2}g^{12}g^{22}\frac{\partial g_{22}}{\partial\xi}$$

$$-\frac{1}{2}(g^{22})^2\frac{\partial g_{22}}{\partial\eta}-g_{11}^{-1}g^{12}\frac{\partial g_{11}}{\partial\xi}-g_{11}^{-1}g^{22}\frac{\partial g_{11}}{\partial\eta}+2(g^{12})^2\frac{\partial g_{12}}{\partial\xi}]\cdot[\int_{z_b}^{z_s}\frac{\partial u}{\partial\eta}dz]$$

$$+g_{11}^{0.5}g_{22}^{-0.5}[(g^{11})^2\frac{\partial g_{11}}{\partial\eta}+2g^{11}g^{12}\frac{\partial g_{12}}{\partial\eta}+(g^{12})^2\frac{\partial g_{22}}{\partial\eta}]\cdot[\int_{z_b}^{z_s}\frac{\partial v}{\partial\xi}dz]$$

$$+g_{11}^{0.5}g_{22}^{-0.5}[g^{11}g^{12}\frac{\partial g_{11}}{\partial\eta}+(g^{12})^2\frac{\partial g_{22}}{\partial\xi}+2g^{11}g^{22}\frac{\partial g_{12}}{\partial\eta}-g^{11}g^{22}\frac{\partial g_{22}}{\partial\xi}+g^{12}g^{22}\frac{\partial g_{22}}{\partial\eta}]\cdot[\int_{z_b}^{z_s}\frac{\partial v}{\partial\eta}dz]$$

$$-\frac{1}{2}[g_{11}^{-1}\frac{\partial g_{11}}{\partial\xi^n}\frac{\partial g^{mn}}{\partial\xi^m}+g^{mn}g_{11}^{-1}\frac{\partial^2 g_{11}}{\partial\xi^m\partial\xi^n}-\frac{3}{2}g^{mn}g_{11}^{-2}\frac{\partial g_{11}}{\partial\xi^n}\frac{\partial g_{11}}{\partial\xi^m}+\Gamma_{nm}^{n}g^{mk}g_{11}^{-1}\frac{\partial g_{11}}{\partial\xi^k}]\cdot\bar{u}h$$

$$+[-g^{mn}g_{11}^{0.5}g_{ss}^{-1.5}\Gamma_{ns}^{1}\frac{\partial g_{ss}}{\partial\xi^m}+\frac{1}{2}g^{mn}g_{11}^{0.5}g_{ss}^{-0.5}(\frac{\partial g_{ks}}{\partial\xi^n}+\frac{\partial g_{kn}}{\partial\xi^s}-\frac{\partial g_{ns}}{\partial\xi^k})\frac{\partial g^{1k}}{\partial\xi^m}$$

$$+\frac{1}{2}g^{mn}g_{11}^{0.5}g_{ss}^{-0.5}g^{1k}(\frac{\partial^2 g_{ks}}{\partial\xi^n\partial\xi^m}+\frac{\partial^2 g_{kn}}{\partial\xi^m\partial\xi^s}-\frac{\partial^2 g_{ns}}{\partial\xi^m\partial\xi^k})$$

$$+g_{11}^{0.5}g_{ss}^{-0.5}\Gamma_{ns}^{1}\frac{\partial g^{mn}}{\partial\xi^m}+g^{mk}g_{11}^{0.5}g_{ss}^{-0.5}\Gamma_{mn}^{n}\Gamma_{ks}^{1}+g^{mk}g_{11}^{0.5}g_{ss}^{-0.5}\Gamma_{kn}^{1}\Gamma_{ms}^{n}]\cdot\overline{V}(s)h$$

$$\}$$

η 方向水流動量方程式：

$$
\begin{aligned}
&\frac{\partial \bar{v}}{\partial t} + g_{11}^{-0.5}\cdot\bar{u}\frac{\partial \bar{v}}{\partial \xi} + g_{22}^{-0.5}\cdot\bar{v}\frac{\partial \bar{v}}{\partial \eta} \\
&+\frac{1}{2}g_{22}^{0.5}g_{11}^{-1}(2g^{22}\frac{\partial g_{12}}{\partial \xi} - g^{22}\frac{\partial g_{11}}{\partial \eta} + g^{12}\frac{\partial g_{11}}{\partial \xi})\cdot[\bar{u}^{2}] \\
&+\frac{1}{2}g_{11}^{-0.5}(g^{22}\frac{\partial g_{22}}{\partial \xi} + g^{12}\frac{\partial g_{11}}{\partial \eta})\cdot[\overline{\bar{u}\bar{v}}] \\
&+\frac{1}{2}g_{11}^{-0.5}(g^{22}\frac{\partial g_{22}}{\partial \xi} + g^{12}\frac{\partial g_{11}}{\partial \eta} - g_{22}^{-1}\frac{\partial g_{22}}{\partial \xi})\cdot[\overline{\bar{u}\bar{v}}] \\
&+\frac{1}{2}g_{22}^{-0.5}(g^{22}\frac{\partial g_{22}}{\partial \eta} + 2g^{12}\frac{\partial g_{12}}{\partial \eta} - g^{12}\frac{\partial g_{22}}{\partial \xi} - g_{22}^{-1}\frac{\partial g_{22}}{\partial \eta})\cdot[\bar{v}^{2}] \\
&+\frac{1}{h}g_{11}^{-0.5}g_{22}^{-0.5}\frac{\partial}{\partial \xi}[g_{22}^{0.5}\frac{1}{N(N+2)}\overline{\bar{u}\bar{v}h}] + \frac{1}{h}g_{11}^{-0.5}g_{22}^{-0.5}\frac{\partial}{\partial \eta}[g_{11}^{0.5}\frac{1}{N(N+2)}\bar{v}^{2}h] \\
&+\frac{1}{2}g_{22}^{0.5}g_{11}^{-1}(2g^{22}\frac{\partial g_{12}}{\partial \xi} - g^{22}\frac{\partial g_{11}}{\partial \eta} + g^{12}\frac{\partial g_{11}}{\partial \xi})\cdot[\frac{1}{N(N+2)}\bar{u}^{2}] \\
&+\frac{1}{2}g_{11}^{-0.5}(g^{22}\frac{\partial g_{22}}{\partial \xi} + g^{12}\frac{\partial g_{11}}{\partial \eta})\cdot[\frac{1}{N(N+2)}\overline{\bar{u}\bar{v}}] \\
&+\frac{1}{2}g_{11}^{-0.5}(g^{22}\frac{\partial g_{22}}{\partial \xi} + g^{12}\frac{\partial g_{11}}{\partial \eta} - g_{22}^{-1}\frac{\partial g_{22}}{\partial \xi})\cdot[\frac{1}{N(N+2)}\overline{\bar{u}\bar{v}}] \\
&+\frac{1}{2}g_{22}^{-0.5}(g^{22}\frac{\partial g_{22}}{\partial \eta} + 2g^{12}\frac{\partial g_{12}}{\partial \eta} - g^{12}\frac{\partial g_{22}}{\partial \xi} - g_{22}^{-1}\frac{\partial g_{22}}{\partial \eta})\cdot[\frac{1}{N(N+2)}\bar{v}^{2}] \\
&+\frac{1}{2}g_{11}^{-0.5}(g^{22}\frac{\partial g_{22}}{\partial \xi} + 2g^{12}\frac{\partial g_{12}}{\partial \xi} + g^{11}\frac{\partial g_{11}}{\partial \xi} - g_{22}^{-1}\frac{\partial g_{22}}{\partial \xi} - g_{11}^{-1}\frac{\partial g_{11}}{\partial \xi})\cdot[\frac{1}{N(N+2)}\overline{\bar{u}\bar{v}}] \\
&+\frac{1}{2}g_{22}^{-0.5}(g^{22}\frac{\partial g_{22}}{\partial \eta} + 2g^{12}\frac{\partial g_{12}}{\partial \eta} + g^{11}\frac{\partial g_{11}}{\partial \eta} - g_{11}^{-1}\frac{\partial g_{11}}{\partial \eta} - g_{22}^{-1}\frac{\partial g_{22}}{\partial \eta})\cdot[\frac{1}{N(N+2)}\bar{v}^{2}] \\
&+\frac{1}{h}g_{22}^{-0.5}\frac{\partial}{\partial \eta}[\int_{z_b}^{z_s}\widetilde{\widetilde{v'^{2}}}\,dz] + \frac{1}{h}g_{11}^{-0.5}\frac{\partial}{\partial \xi}[\int_{z_b}^{z_s}\widetilde{\widetilde{u'v'}}\,dz] \\
&+\frac{1}{2h}g_{22}^{-0.5}[2g^{22}\frac{\partial g_{22}}{\partial \eta} + 4g^{12}\frac{\partial g_{12}}{\partial \eta} - g^{12}\frac{\partial g_{22}}{\partial \xi} + g^{11}\frac{\partial g_{11}}{\partial \eta} - 2g_{22}^{-1}\frac{\partial g_{22}}{\partial \eta}]\int_{z_b}^{z_s}\widetilde{\widetilde{v'^{2}}}\,dz \\
&+\frac{1}{2h}g_{11}^{-0.5}[3g^{22}\frac{\partial g_{22}}{\partial \xi} + 2g^{12}\frac{\partial g_{11}}{\partial \eta} - g_{22}^{-1}\frac{\partial g_{22}}{\partial \xi} - g_{11}^{-1}\frac{\partial g_{11}}{\partial \xi} + 2g^{12}\frac{\partial g_{12}}{\partial \xi} + g^{11}\frac{\partial g_{11}}{\partial \xi}]\int_{z_b}^{z_s}\widetilde{\widetilde{u'v'}}\,dz \\
&+\frac{1}{2h}g_{22}^{0.5}g_{11}^{-1}[2g^{22}\frac{\partial g_{12}}{\partial \xi} - g^{22}\frac{\partial g_{11}}{\partial \eta} + g^{12}\frac{\partial g_{11}}{\partial \xi}]\int_{z_b}^{z_s}\widetilde{\widetilde{u'^{2}}}\,dz
\end{aligned}
$$

$$= -g \cdot g_{22}^{0.5} g^{22} \frac{\partial (z_b + h)}{\partial \eta} - g \cdot g_{22}^{0.5} g^{12} \frac{\partial (z_b + h)}{\partial \xi}$$

$$+ \frac{\nu}{h} \cdot \{$$

$$g^{22} \frac{\partial}{\partial \eta} [\int_{z_b}^{z_s} \frac{\partial v}{\partial \eta} dz] - g^{22} [\frac{\partial v_s}{\partial \eta} \frac{\partial z_s}{\partial \eta}] + 2g^{12} \frac{\partial}{\partial \eta} [\int_{z_b}^{z_s} \frac{\partial v}{\partial \xi} dz]$$

$$- 2g^{12} [\frac{\partial v_s}{\partial \xi} \frac{\partial z_s}{\partial \eta}] + g^{11} \frac{\partial}{\partial \xi} [\int_{z_b}^{z_s} \frac{\partial v}{\partial \xi} dz] - g^{11} [\frac{\partial v_s}{\partial \xi} \frac{\partial z_s}{\partial \xi}] + \frac{\partial v_s}{\partial z} - \frac{\partial v_b}{\partial z}$$

$$+ [\frac{1}{2} (g^{22})^2 \frac{\partial g_{22}}{\partial \eta} + g^{22} g^{12} \frac{\partial g_{12}}{\partial \eta} - \frac{1}{2} g^{22} g^{12} \frac{\partial g_{22}}{\partial \xi} - g^{11} g^{22} \frac{\partial g_{12}}{\partial \xi}$$

$$+ \frac{1}{2} g^{11} g^{22} \frac{\partial g_{11}}{\partial \eta} - \frac{1}{2} g^{12} g^{11} \frac{\partial g_{11}}{\partial \xi} - g_{22}^{-1} g^{22} \frac{\partial g_{22}}{\partial \eta} - g_{22}^{-1} g^{12} \frac{\partial g_{22}}{\partial \xi}] \cdot [\int_{z_b}^{z_s} \frac{\partial v}{\partial \eta} dz]$$

$$+ [\frac{1}{2} g^{22} g^{12} \frac{\partial g_{22}}{\partial \eta} - g^{11} g^{22} \frac{\partial g_{12}}{\partial \eta} + \frac{3}{2} g^{11} g^{22} \frac{\partial g_{22}}{\partial \xi} - 2(g^{12})^2 \frac{\partial g_{22}}{\partial \xi} - g^{12} g^{11} \frac{\partial g_{12}}{\partial \xi}$$

$$+ \frac{1}{2} g^{12} g^{11} \frac{\partial g_{11}}{\partial \eta} - \frac{1}{2} (g^{11})^2 \frac{\partial g_{11}}{\partial \xi} - g_{22}^{-1} g^{12} \frac{\partial g_{22}}{\partial \eta} - g_{22}^{-1} g^{11} \frac{\partial g_{22}}{\partial \xi} + 2(g^{12})^2 \frac{\partial g_{12}}{\partial \eta}] \cdot [\int_{z_b}^{z_s} \frac{\partial v}{\partial \xi} dz]$$

$$+ g_{22}^{0.5} g_{11}^{-0.5} [(g^{22})^2 \frac{\partial g_{22}}{\partial \xi} + 2g^{22} g^{12} \frac{\partial g_{12}}{\partial \xi} + (g^{12})^2 \frac{\partial g_{11}}{\partial \xi}] \cdot [\int_{z_b}^{z_s} \frac{\partial u}{\partial \eta} dz]$$

$$+ g_{22}^{0.5} g_{11}^{-0.5} [g^{22} g^{12} \frac{\partial g_{22}}{\partial \xi} + (g^{12})^2 \frac{\partial g_{11}}{\partial \eta} + 2g^{11} g^{22} \frac{\partial g_{12}}{\partial \xi} - g^{11} g^{22} \frac{\partial g_{11}}{\partial \eta} + g^{12} g^{11} \frac{\partial g_{11}}{\partial \xi}] \cdot [\int_{z_b}^{z_s} \frac{\partial u}{\partial \xi} dz]$$

$$- \frac{1}{2} [g_{22}^{-1} \frac{\partial g_{22}}{\partial \xi^n} \frac{\partial g^{mn}}{\partial \xi^m} + g^{mn} g_{22}^{-1} \frac{\partial^2 g_{22}}{\partial \xi^m \partial \xi^n} - \frac{3}{2} g^{mn} g_{22}^{-2} \frac{\partial g_{22}}{\partial \xi^n} \frac{\partial g_{22}}{\partial \xi^m} + \Gamma_{nm}^n g^{mk} g_{22}^{-1} \frac{\partial g_{22}}{\partial \xi^k}] \cdot \bar{v} h$$

$$+ [-g^{mn} g_{22}^{0.5} g_{ss}^{-1.5} \Gamma_{ns}^2 \frac{\partial g_{ss}}{\partial \xi^m} + \frac{1}{2} g^{mn} g_{22}^{0.5} g_{ss}^{-0.5} (\frac{\partial g_{ks}}{\partial \xi^n} + \frac{\partial g_{kn}}{\partial \xi^s} - \frac{\partial g_{ns}}{\partial \xi^k}) \frac{\partial g^{2k}}{\partial \xi^m}$$

$$+ \frac{1}{2} g^{mn} g_{22}^{0.5} g_{ss}^{-0.5} g^{2k} (\frac{\partial^2 g_{ks}}{\partial \xi^n \partial \xi^m} + \frac{\partial^2 g_{kn}}{\partial \xi^m \partial \xi^s} - \frac{\partial^2 g_{ns}}{\partial \xi^m \partial \xi^k})$$

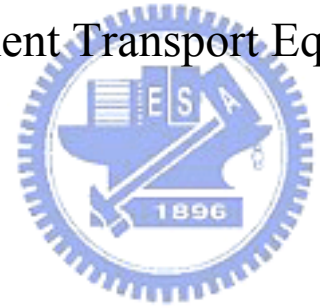
$$+ g_{22}^{0.5} g_{ss}^{-0.5} \Gamma_{ns}^2 \frac{\partial g^{mn}}{\partial \xi^m} + g^{mk} g_{22}^{0.5} g_{ss}^{-0.5} \Gamma_{mn}^n \Gamma_{ks}^2 + g^{mk} g_{22}^{0.5} g_{ss}^{-0.5} \Gamma_{kn}^2 \Gamma_{ms}^n] \cdot \bar{V}(s) h$$

$$\}$$

其中，m、n、k及s，為累加指標；下標s與b分別表示水面與底床位置；h為水深。

附錄二 輸砂控制方程式

(Sediment Transport Equations)



懸浮載質量守恆方程式：

$$\frac{\partial \bar{c}}{\partial t}+g_{11}^{-0.5}\bar{u}\frac{\partial \bar{c}}{\partial \xi}+g_{22}^{-0.5}\bar{v}\frac{\partial \bar{c}}{\partial \eta}=-\{g_{11}^{-0.5}g_{22}^{-0.5}\frac{\partial[g_{22}^{0.5}\cdot Q_{s_1}]}{\partial \xi}+g_{11}^{-0.5}g_{22}^{-0.5}\frac{\partial[g_{11}^{0.5}\cdot Q_{s_2}]}{\partial \eta}$$
$$+\frac{1}{2}g_{11}^{-0.5}\left(g^{11}\frac{\partial g_{11}}{\partial \xi}+2g^{12}\frac{\partial g_{12}}{\partial \xi}+g^{22}\frac{\partial g_{22}}{\partial \xi}-g_{22}^{-1}\frac{\partial g_{22}}{\partial \xi}-g_{11}^{-1}\frac{\partial g_{11}}{\partial \xi}\right)\cdot Q_{s_1}$$
$$+\frac{1}{2}g_{22}^{-0.5}\left(g^{11}\frac{\partial g_{11}}{\partial \eta}+2g^{12}\frac{\partial g_{12}}{\partial \eta}+g^{22}\frac{\partial g_{22}}{\partial \eta}-g_{11}^{-1}\frac{\partial g_{11}}{\partial \eta}-g_{22}^{-1}\frac{\partial g_{22}}{\partial \eta}\right)\cdot Q_{s_2}\}$$
$$+\frac{S}{(h-\delta_a)}$$
$$=0$$

作用層質量守恆方程式：

$$\rho_s(1-p)\frac{\partial(\beta_k E_m)}{\partial t}$$
$$+\left\{\begin{array}{l} g_{11}^{-0.5}g_{22}^{-0.5}\frac{\partial[g_{22}^{0.5}\cdot q_{b_1}]}{\partial \xi}+g_{11}^{-0.5}g_{22}^{-0.5}\frac{\partial[g_{11}^{0.5}\cdot q_{b_2}]}{\partial \eta} \\ +\frac{1}{2}g_{11}^{-0.5}\left(g^{11}\frac{\partial g_{11}}{\partial \xi}+2g^{12}\frac{\partial g_{12}}{\partial \xi}+g^{22}\frac{\partial g_{22}}{\partial \xi}-g_{22}^{-1}\frac{\partial g_{22}}{\partial \xi}-g_{11}^{-1}\frac{\partial g_{11}}{\partial \xi}\right)\cdot q_{b_1} \\ +\frac{1}{2}g_{22}^{-0.5}\left(g^{11}\frac{\partial g_{11}}{\partial \eta}+2g^{12}\frac{\partial g_{12}}{\partial \eta}+g^{22}\frac{\partial g_{22}}{\partial \eta}-g_{11}^{-1}\frac{\partial g_{11}}{\partial \eta}-g_{22}^{-1}\frac{\partial g_{22}}{\partial \eta}\right)\cdot q_{b_2} \\ +\rho_s(S-S_f) \end{array}\right\}_k \quad k=1,\cdots\cdots,TK$$
$$=0$$

整體河床輸砂質量守恆方程式：

$$\rho_s(1-p)\frac{\partial(Z_b)}{\partial t}$$
$$+\sum_{k=1}^{TK}\left\{\begin{array}{l} g_{11}^{-0.5}g_{22}^{-0.5}\dfrac{\partial[g_{22}^{0.5}\cdot q_{b_1}]}{\partial\xi}+g_{11}^{-0.5}g_{22}^{-0.5}\dfrac{\partial[g_{11}^{0.5}\cdot q_{b_2}]}{\partial\eta} \\ +\dfrac{1}{2}g_{11}^{-0.5}\left(g^{11}\dfrac{\partial g_{11}}{\partial\xi}+2g^{12}\dfrac{\partial g_{12}}{\partial\xi}+g^{22}\dfrac{\partial g_{22}}{\partial\xi}-g_{22}^{-1}\dfrac{\partial g_{22}}{\partial\xi}-g_{11}^{-1}\dfrac{\partial g_{11}}{\partial\xi}\right)\cdot q_{b_1} \\ +\dfrac{1}{2}g_{22}^{-0.5}\left(g^{11}\dfrac{\partial g_{11}}{\partial\eta}+2g^{12}\dfrac{\partial g_{12}}{\partial\eta}+g^{22}\dfrac{\partial g_{22}}{\partial\eta}-g_{11}^{-1}\dfrac{\partial g_{11}}{\partial\eta}-g_{22}^{-1}\dfrac{\partial g_{22}}{\partial\eta}\right)\cdot q_{b_2} \\ +\rho_s S \end{array}\right\}_k \qquad k=1,\cdots\cdots,TK$$
$$=0$$

其中，Q_s為水流方向紊流擴散項；下標 1,2 分別表示ξ-和η-方向之物理量。

表 1 阿公店溪各計畫斷面相關資料表

（公尺）

斷面	計畫 堤頂高	計畫 渠底高	堤頂河寬	底床坡度	河心單距	河心累距
1	5	-1.1	110	2.04499E-04	0	0
2	5	-1	110	1.84049E-04	489	489
3	5	-0.94	110	2.02492E-04	326	815
4	5	-0.81	110	2.09424E-04	642	1457
5	5	-0.69	110	1.99637E-04	573	2030
6	5.24	-0.58	110	1.82768E-04	551	2581
7	5.37	-0.51	110	2.17391E-04	383	2964
10	5.69	-0.43	110	2.13220E-04	409	3373
11	5.8	-0.33	110	2.05761E-04	469	3842
12	5.93	-0.23	110	1.91489E-04	486	4328
13	6.04	-0.14	110	1.95382E-04	470	4798
14	6.18	-0.03	110	1.97842E-04	563	5361
15	6.32	0.08	110	2.01511E-04	556	5917
16	6.42	0.16	110	2.17984E-04	397	6314
17	6.51	0.24	110	1.89873E-04	367	6681
18	6.67	0.36	110	8.37563E-04	632	7313
19	7.15	0.69	110	8.66667E-04	394	7707
19.1	7.17	0.755	95	8.66667E-04	75	7782
19.2	7.19	0.82	80	8.66667E-04	75	7857
19.3	7.21	0.885	65	8.90411E-04	75	7932
20	7.23	0.95	50	8.73181E-04	73	8005
21	7.34	1.37	50	8.85827E-04	481	8486
22	7.47	1.82	50	8.99281E-04	508	8994
23	7.54	2.07	50	8.65140E-04	278	9272
24	7.64	2.41	50	3.00000E-04	393	9665
25	7.71	2.5	50	2.90557E-04	300	9965
26	7.81	2.62	50	3.16206E-04	413	10378
27	8.17	2.78	50	3.38710E-04	506	10884
28	8.29	2.99	50	3.38983E-04	620	11504
29	8.38	3.13	50	2.51256E-04	413	11917

表 1（續） 阿公店溪各計畫斷面相關資料表

（公尺）

斷面	計畫堤頂高	計畫渠底高	堤頂河寬	底床坡度	河心單距	河心累距
30.1	8.41	3.18	50	0.006534653	158	12075
31.1	8.41	3.84	42	0.003958333	101	12176
32.1	8.41	4.22	35	0.002329843	96	12272
33	8.41	5.11	35	5.95238E-04	382	12654
34	9.22	5.31	35	7.42857E-04	336	12990
35.1	9.87	5.57	35	4.00000E-03	350	13340
35.3	9.86	5.61	35	0.003662551	10	13350
36	10.71	6.5	35	0.003472222	243	13593
37	11.29	8	35	3.81679E-04	432	14025
38	11.69	8.1	35	6.94444E-04	262	14287
39	11.89	8.2	35	3.33333E-04	144	14431
40	12.14	8.28	35	0.00115942	240	14671
41	12.58	8.92	35	0.001463415	552	15223
42	12.89	9.4	35	4.50450E-04	328	15551
43	13.96	9.6	35	3.08880E-04	444	15995
44	15.07	9.68	35	5.00000E-03	259	16254
45	15.17	10.76	35	0.002619048	216	16470
46	15.39	11.2	35	0.001028807	168	16638
47	15.81	11.45	35	1.19048E-04	243	16881
48	16.25	11.47	35	1.50000E-03	168	17049
49	16.53	11.65	35	0.002083333	120	17169
50	16.62	11.75	35	5.20833E-04	48	17217
51	16.8	11.8	35	3.92157E-04	96	17313
52	16.99	11.88	35	6.63507E-04	204	17517
53	17.09	12.02	35	1.92308E-04	211	17728
54	17.19	12.05	35	4.86111E-04	156	17884
55	17.22	12.12	35	0.003958333	144	18028
56	17.35	12.5	35	0.002777778	96	18124
57	17.42	12.8	35	4.16667E-04	108	18232
58	17.44	12.85	35	3.57143E-04	120	18352
59	17.58	12.88	35	3.57143E-04	84	18436

表 2 阿公店溪各斷面代表粒徑組成百分比

（摘自「阿公店水庫更新改善計畫先期作業規劃專題報告四」）

斷面	D1=0.003873mm	D2=0.02738mm	D3=0.172mm	D4=0.239mm	D5=0.334mm	D6=0.5mm	D7=1.0mm	備註
1	0.010	0.079	0.241	0.358	0.250	0.062	0.000	
2	0.017	0.146	0.255	0.227	0.181	0.125	0.049	
3	0.018	0.239	0.324	0.259	0.160	0.000	0.000	
4	0.038	0.357	0.357	0.059	0.083	0.080	0.028	
5	0.021	0.300	0.399	0.198	0.082	0.000	0.000	
6	0.017	0.169	0.294	0.226	0.153	0.102	0.039	
7	0.020	0.242	0.356	0.172	0.117	0.083	0.010	
8	0.019	0.224	0.342	0.187	0.132	0.086	0.010	
9	0.017	0.185	0.294	0.214	0.168	0.098	0.023	
10	0.020	0.281	0.360	0.127	0.092	0.090	0.031	
11	0.038	0.328	0.358	0.099	0.108	0.068	0.000	
12	0.036	0.298	0.350	0.119	0.109	0.079	0.010	
13	0.034	0.257	0.338	0.146	0.101	0.093	0.032	
14	0.019	0.169	0.307	0.227	0.140	0.102	0.037	
15	0.018	0.179	0.259	0.189	0.171	0.130	0.054	
16	0.504	0.278	0.120	0.064	0.033	0.000	0.000	
17	0.018	0.095	0.130	0.114	0.216	0.231	0.198	
18	0.018	0.151	0.267	0.227	0.116	0.075	0.146	
19	0.020	0.198	0.293	0.182	0.094	0.089	0.125	
20	0.039	0.259	0.312	0.137	0.118	0.099	0.036	

表 2（續） 阿公店溪各斷面代表粒徑組成百分比

（摘自「阿公店水庫更新改善計畫先期作業規劃專題報告四」）

斷面	D1=0.003873mm	D2=0.02738mm	D3=0.172mm	D4=0.239mm	D5=0.334mm	D6=0.5mm	D7=1.0mm
21	0.017	0.140	0.270	0.253	0.169	0.106	0.046
22	0.344	0.294	0.165	0.048	0.078	0.060	0.010
23	0.019	0.194	0.299	0.183	0.078	0.053	0.174
24	0.021	0.314	0.370	0.109	0.102	0.075	0.010
25	0.177	0.326	0.262	0.024	0.039	0.098	0.073
26	0.019	0.234	0.353	0.198	0.131	0.066	0.000
27	0.016	0.151	0.301	0.243	0.140	0.104	0.045
28	0.020	0.236	0.322	0.162	0.131	0.099	0.031
29	0.019	0.239	0.351	0.149	0.051	0.110	0.082
30	0.010	0.062	0.135	0.171	0.211	0.183	0.229
31	0.142	0.213	0.233	0.130	0.064	0.076	0.141
32	0.207	0.247	0.207	0.080	0.047	0.083	0.129
33	0.026	0.156	0.247	0.213	0.231	0.128	0.000
36	0.024	0.133	0.185	0.157	0.183	0.207	0.112
39	0.033	0.186	0.232	0.133	0.131	0.177	0.107
42	0.014	0.078	0.102	0.107	0.205	0.314	0.180
45	0.014	0.077	0.097	0.098	0.211	0.324	0.180
48	0.022	0.119	0.234	0.255	0.187	0.122	0.060
51	0.041	0.245	0.296	0.160	0.168	0.090	0.000
54	0.028	0.148	0.178	0.120	0.145	0.129	0.253
57	0.016	0.084	0.106	0.106	0.187	0.253	0.248

表 3　阿公店溪河口 100 年頻率潮位資料

單位:公尺

小時	天文潮	暴潮偏差	暴潮位
1	0.2673	0.0600	0.3273
2	0.1846	0.0700	0.2546
3	0.0747	0.0800	0.1547
4	-0.0339	0.0900	0.0561
5	-0.1131	0.1000	-0.0131
6	-0.1420	0.1100	-0.0320
7	-0.1120	0.1300	0.0180
8	-0.0286	0.1400	0.1114
9	0.0897	0.1800	0.2697
10	0.2162	0.2200	0.4362
11	0.3223	0.3300	0.6523
12	0.3841	0.6450	1.0291
13	0.3881	1.4300	1.8181
14	0.3339	0.7950	1.1289
15	0.2341	0.4800	0.7141
16	0.1108	0.3400	0.4508
17	-0.0098	0.2500	0.2402
18	-0.1033	0.2000	0.0967
19	-0.1530	0.1700	0.0170
20	-0.1534	0.1450	-0.0084
21	-0.1102	0.1300	0.0198
22	-0.0391	0.1200	0.0809
23	0.0395	0.1100	0.1495
24	0.1049	0.1000	0.2049
25	0.1422	0.0900	0.2322
26	0.1449	0.0800	0.2249
27	0.1166	0.0700	0.1866
28	0.0697	0.0600	0.1297
29	0.0213	0.0500	0.0713
30	-0.0109	0.0400	0.0291
31	-0.0135	0.0300	0.0165

32	0.0190	0.0200	0.0390
33	0.0829	0.0100	0.0929
34	0.1660	0.0000	0.1660
35	0.2510	0.0000	0.2510
36	0.3189	0.0000	0.3189

註:上表為民國 83 年 8 月 12 日 12 時至 8 月 13 日 23 時道格颱洪(約 100 年頻率)之暴潮位推估值

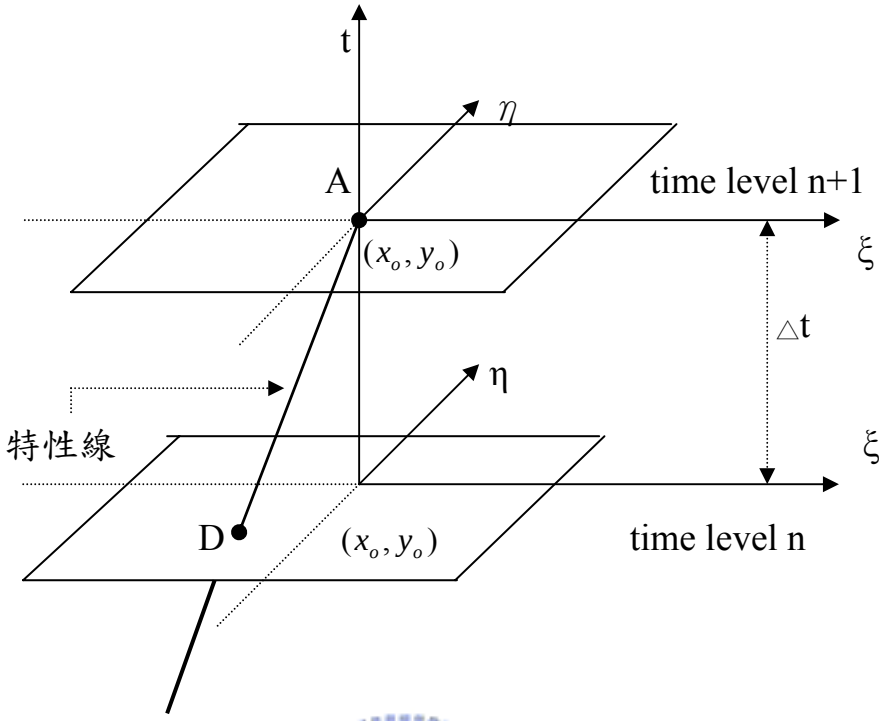


圖 1 EFA 模式之特性線運動軌跡

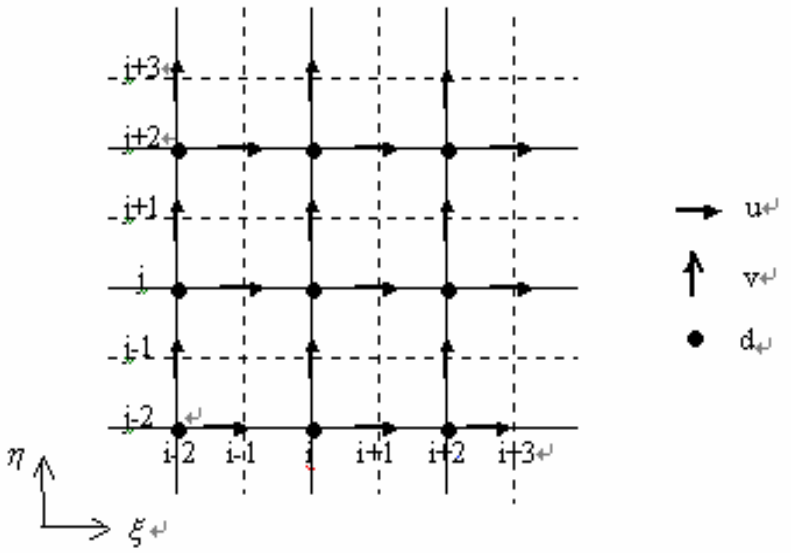


圖 2 交錯式計算格點

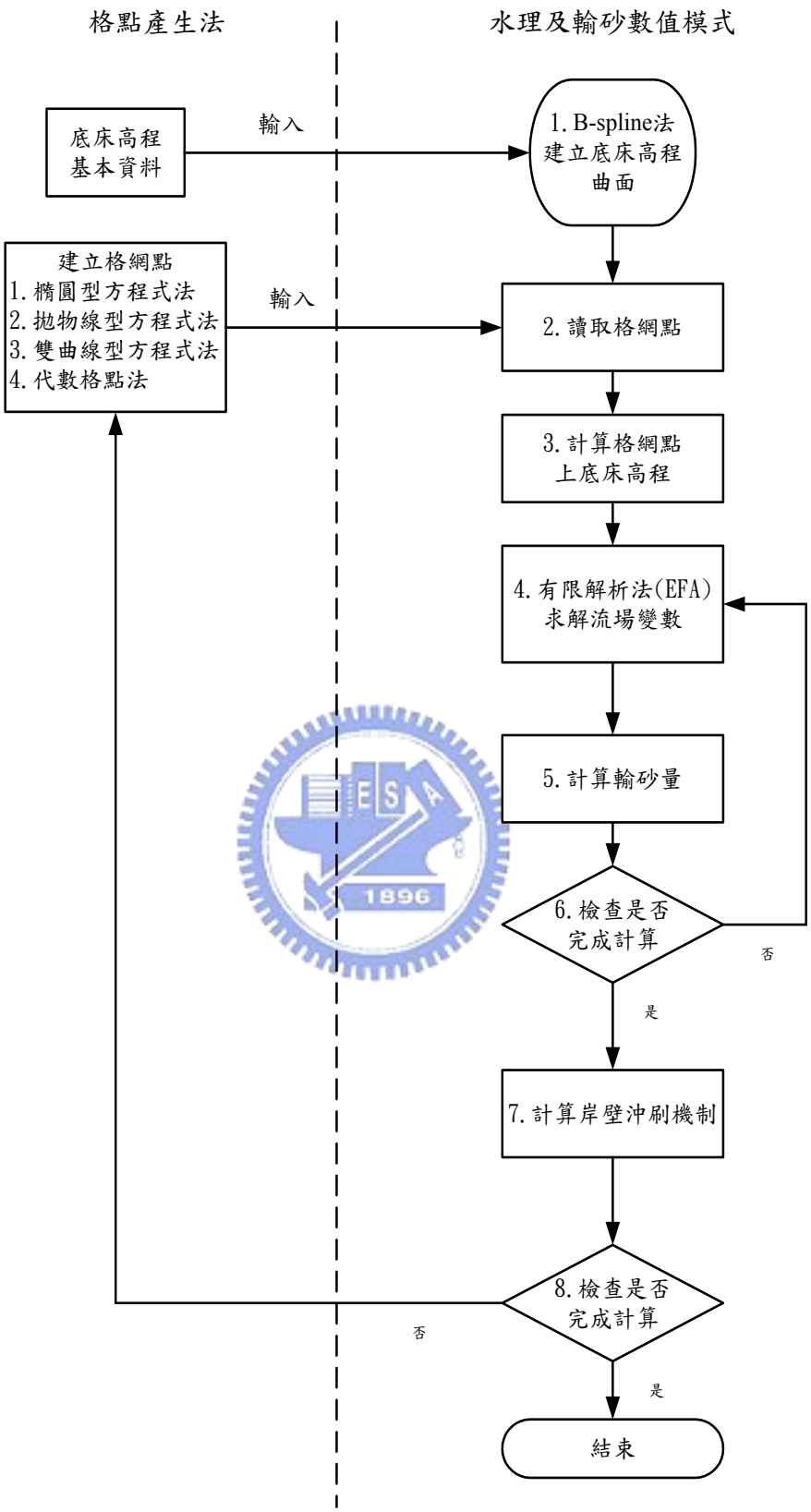


圖 3 EFA 模式演算流程

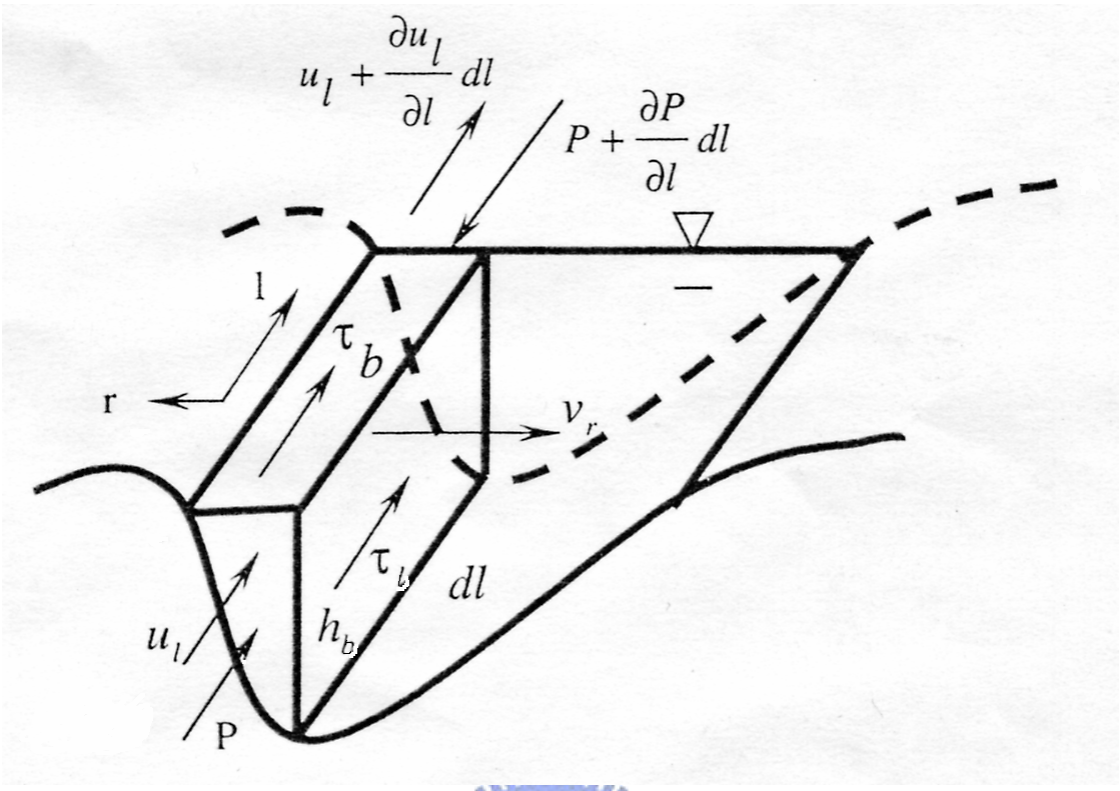


圖 4 近岸動量平衡情形

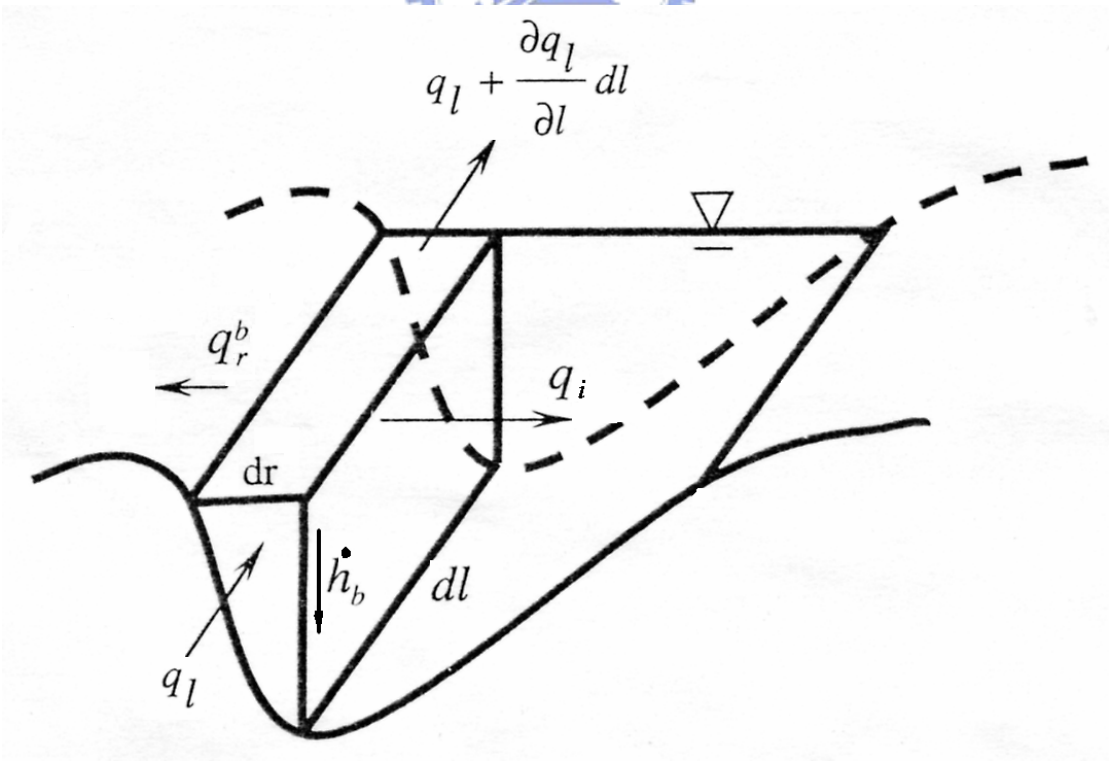


圖 5 近岸輸砂通量平衡情形

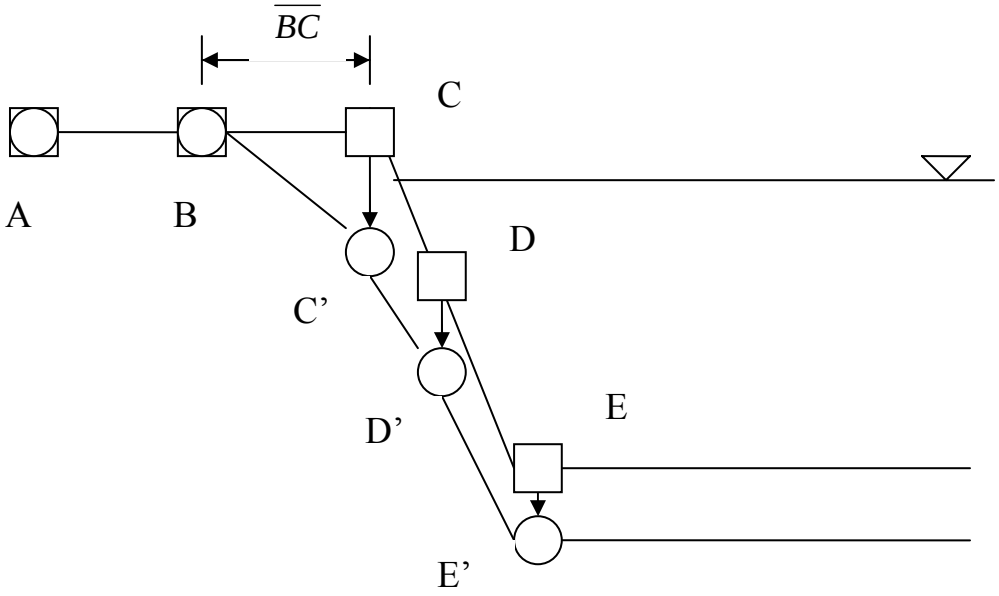


圖 6 岸壁前進（或後退）之距離

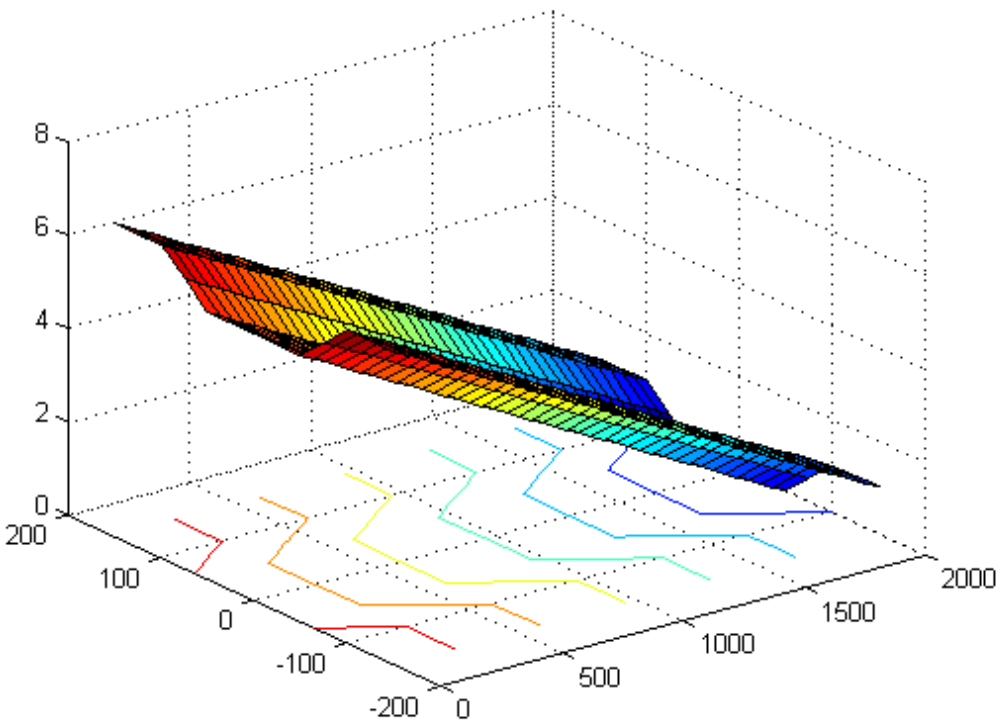


圖 7 原始底床高程

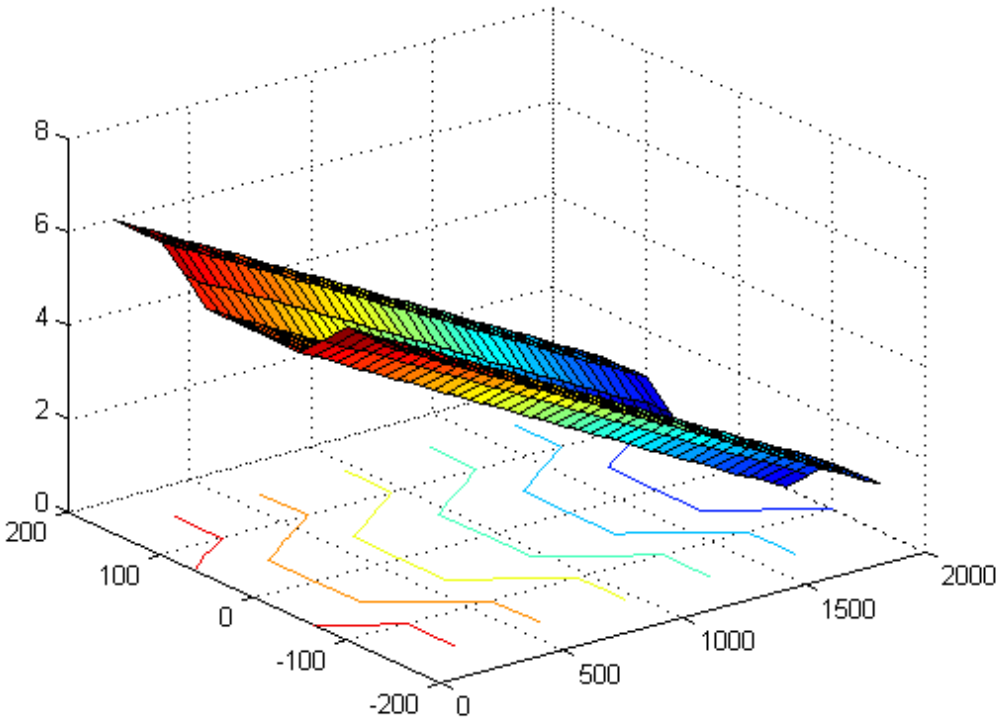


圖 8 10 分鐘後底床高程（使用岸壁沖刷機制）

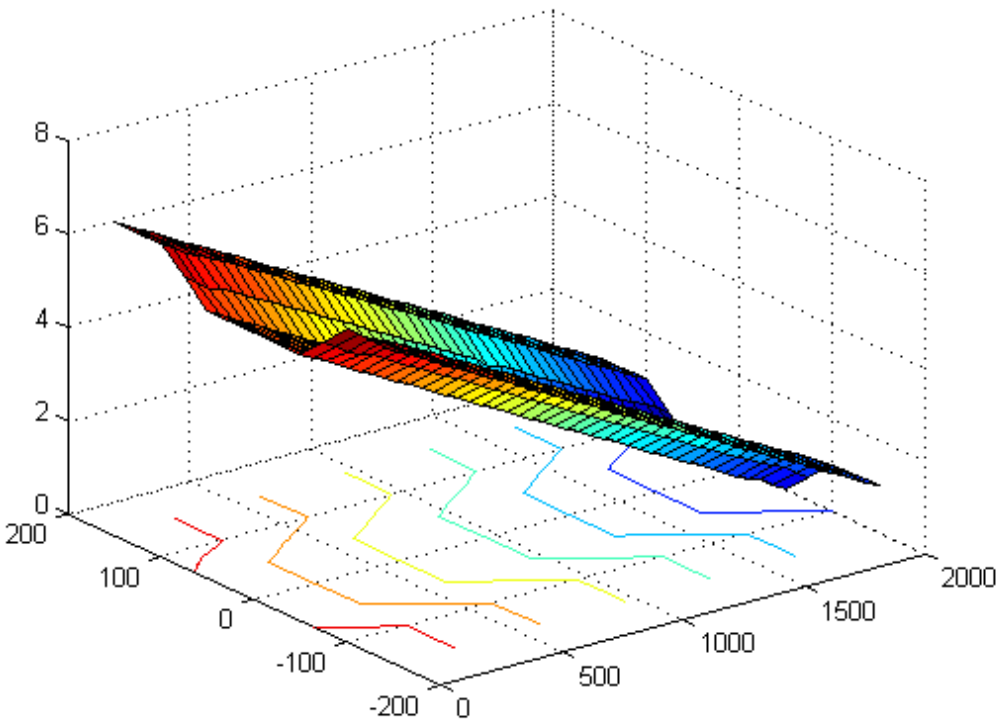


圖 9 20 分鐘後底床高程（使用岸壁沖刷機制）

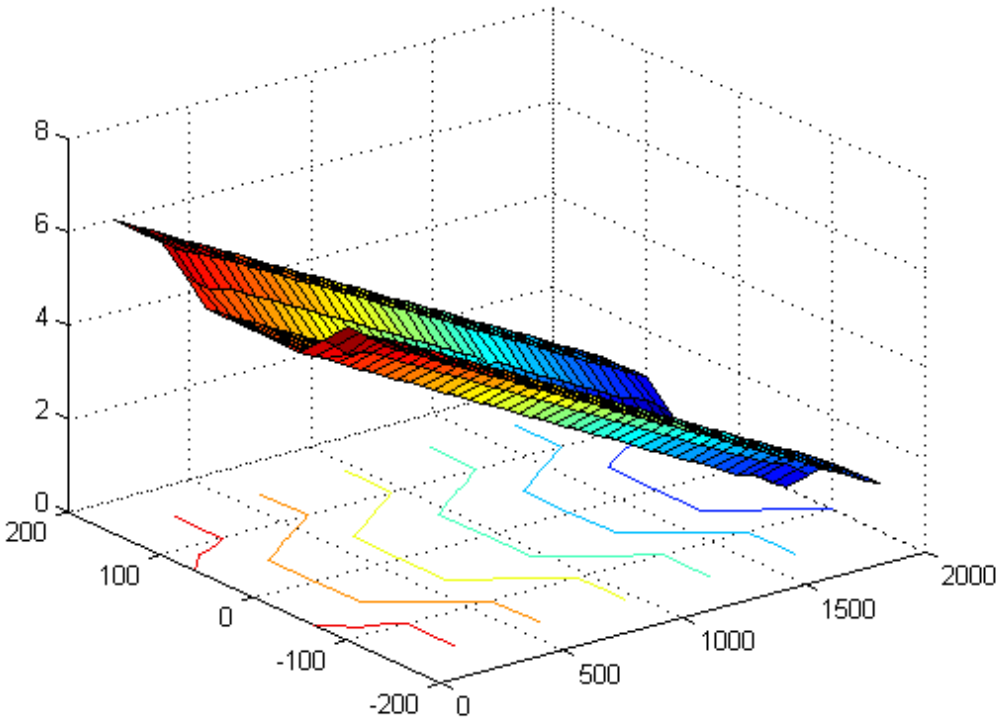


圖 10 30 分鐘後底床高程（使用岸壁沖刷機制）

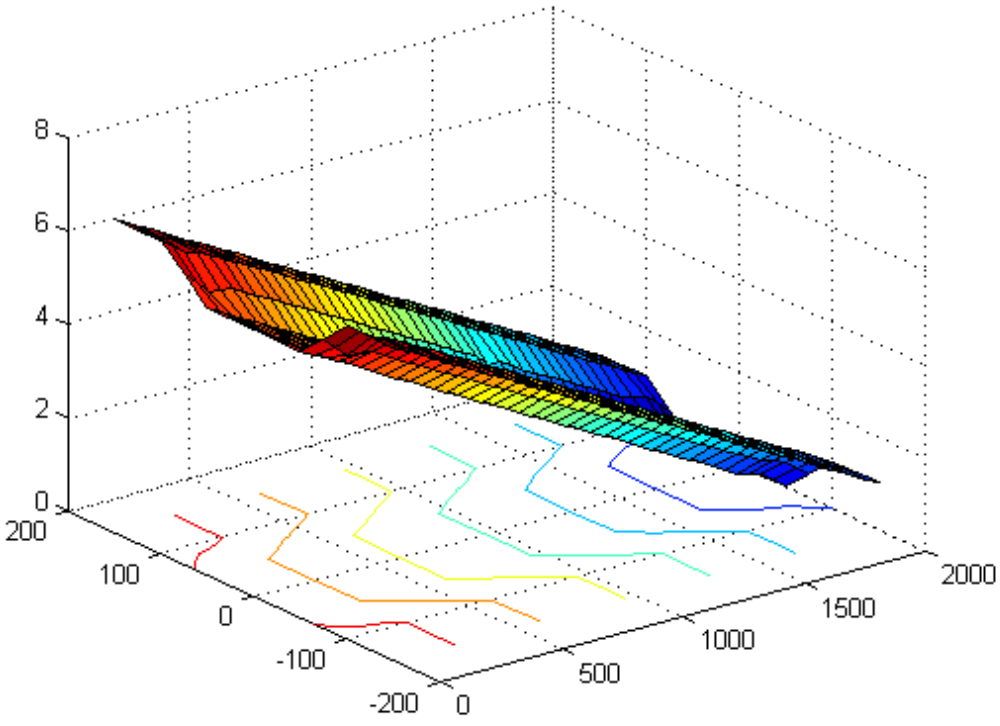


圖 11 40 分鐘後底床高程（使用岸壁沖刷機制）

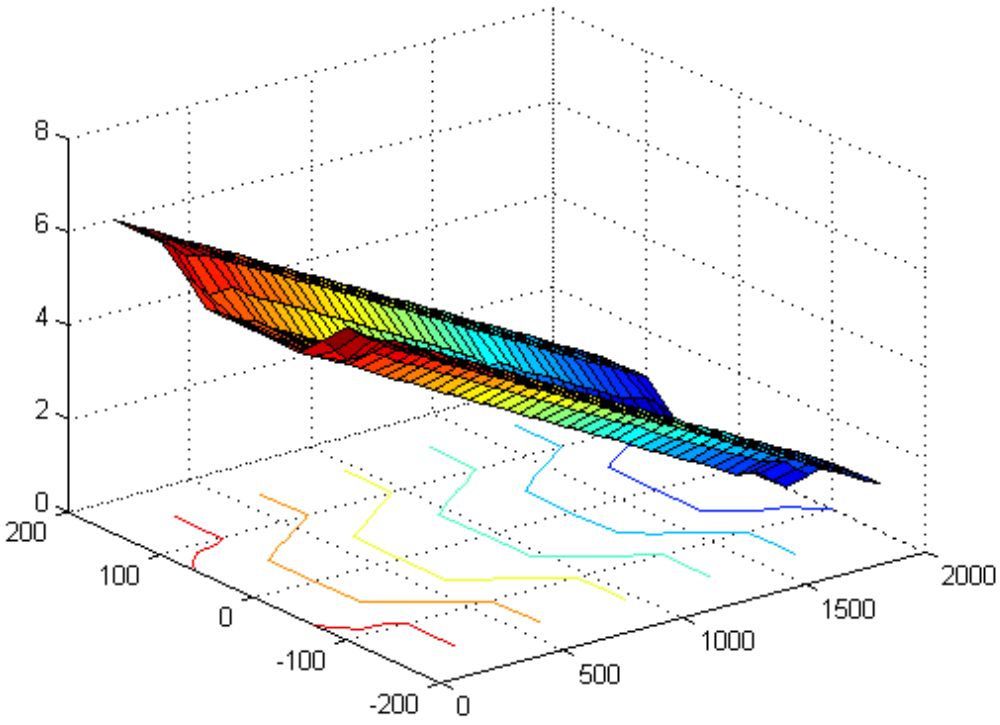


圖 12 50 分鐘後底床高程（使用岸壁沖刷機制）

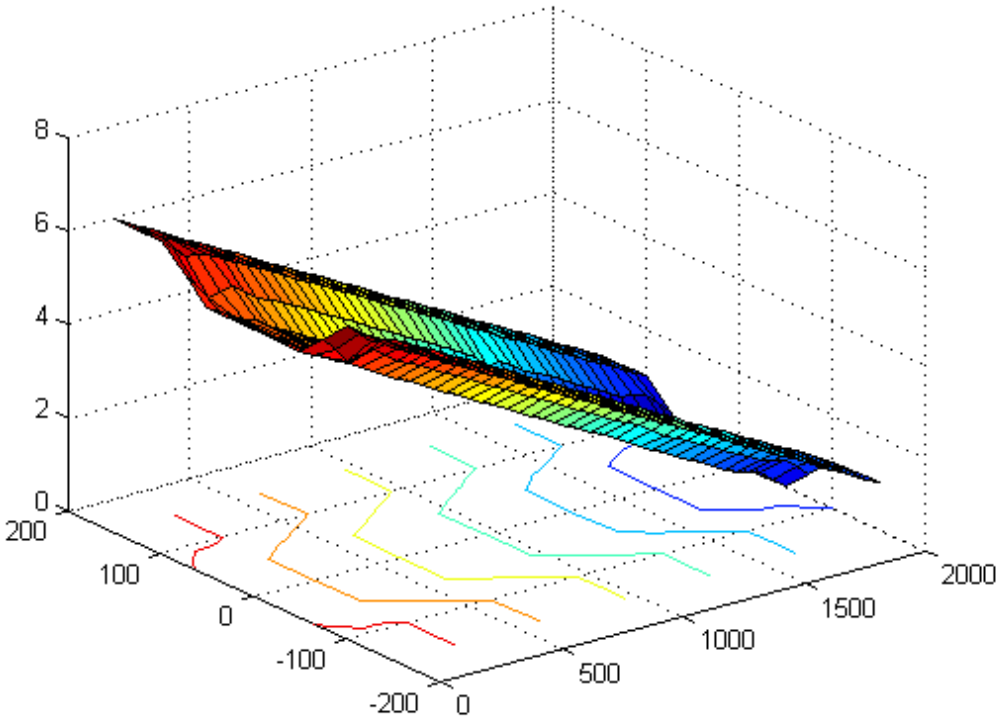


圖 13 60 分鐘後底床高程（使用岸壁沖刷機制）

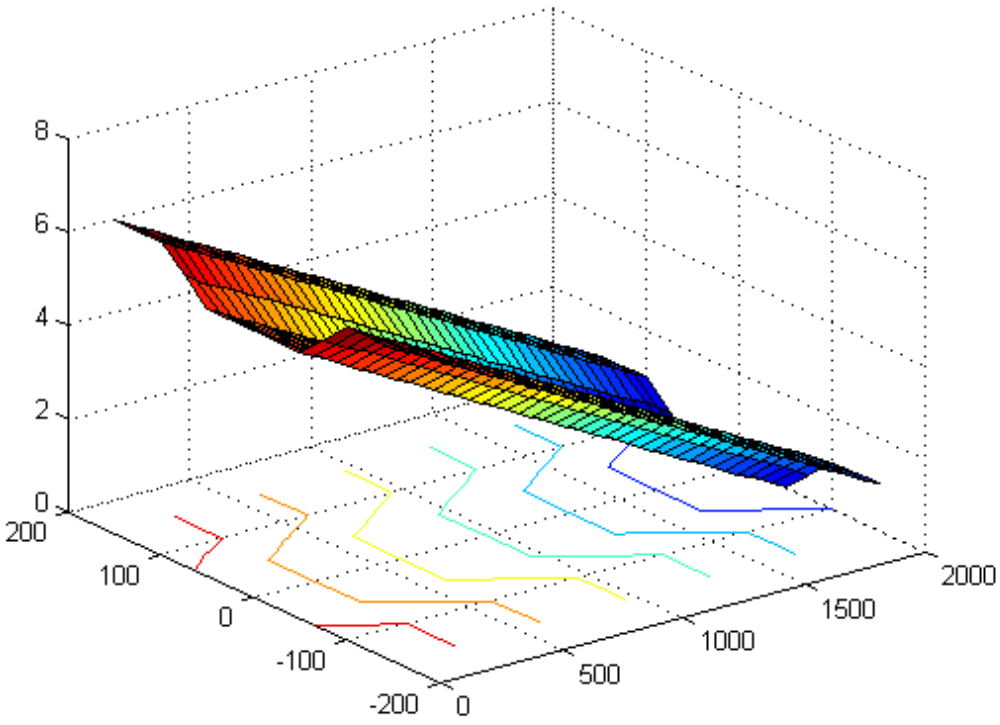


圖 14 10 分鐘後底床高程(非凝聚性沈滓，c=3000ppm)

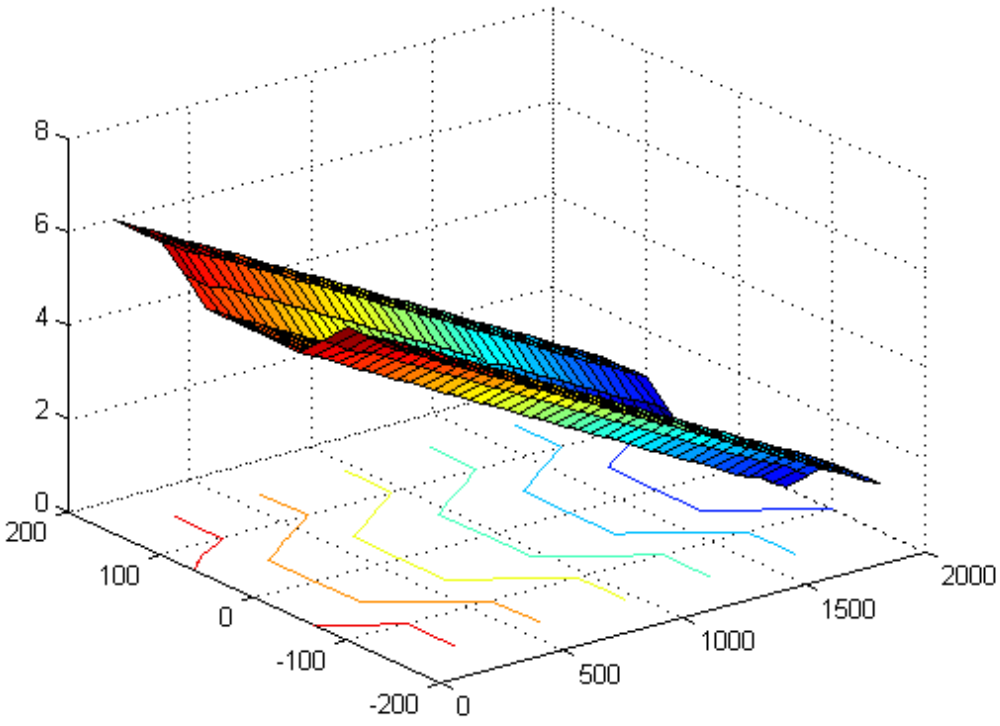


圖 15 20 分鐘後底床高程(非凝聚性沈滓，c=3000ppm)

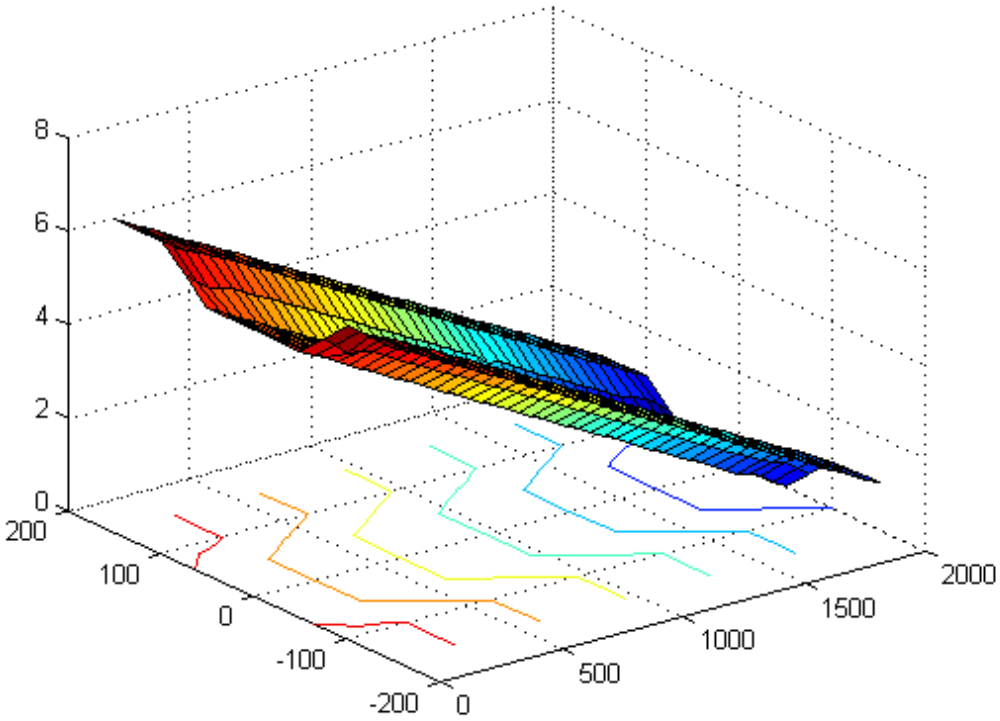


圖 16 30 分鐘後底床高程(非凝聚性沈滓，c=3000ppm)

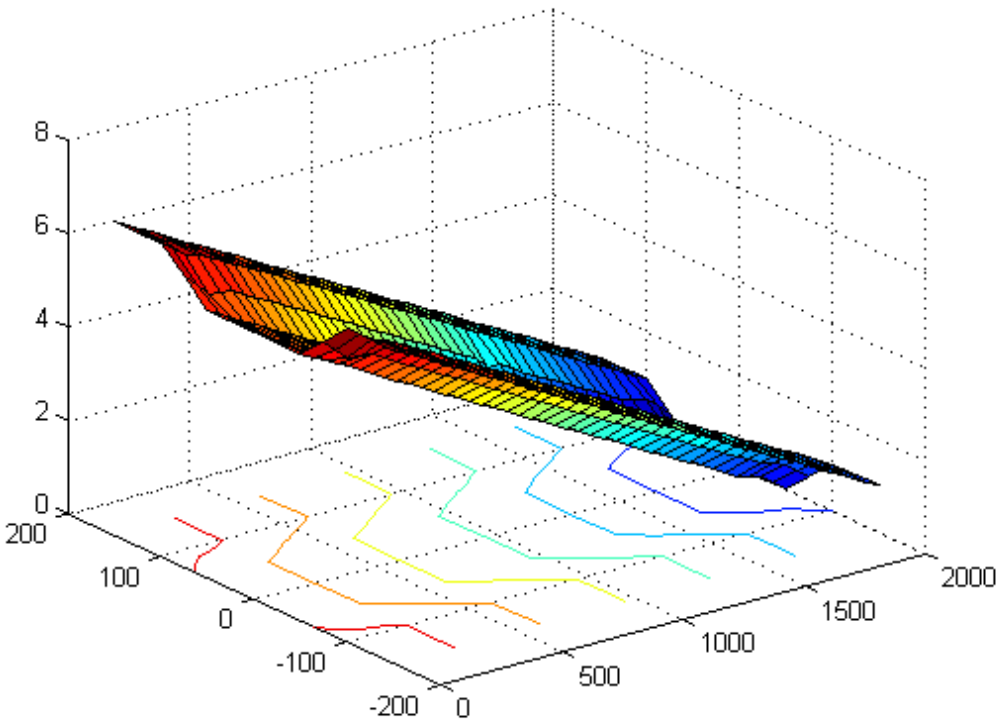


圖 17 40 分鐘後底床高程(非凝聚性沈滓，c=3000ppm)

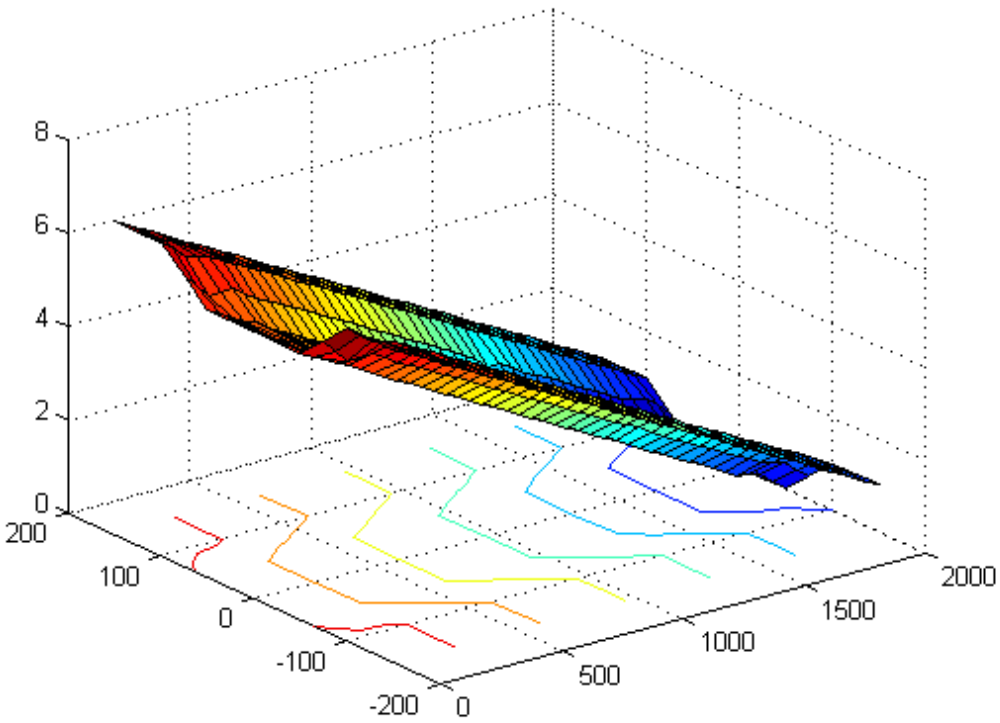


圖 18 50 分鐘後底床高程(非凝聚性沈滓，c=3000ppm)

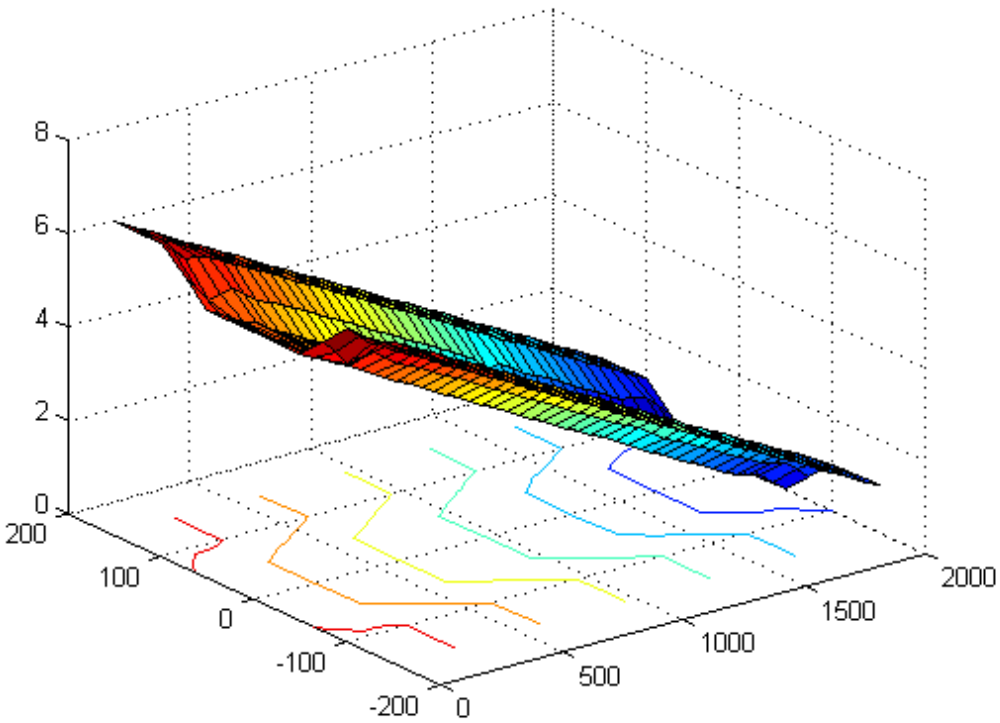


圖 19 60 分鐘後底床高程(非凝聚性沈滓，c=3000ppm)

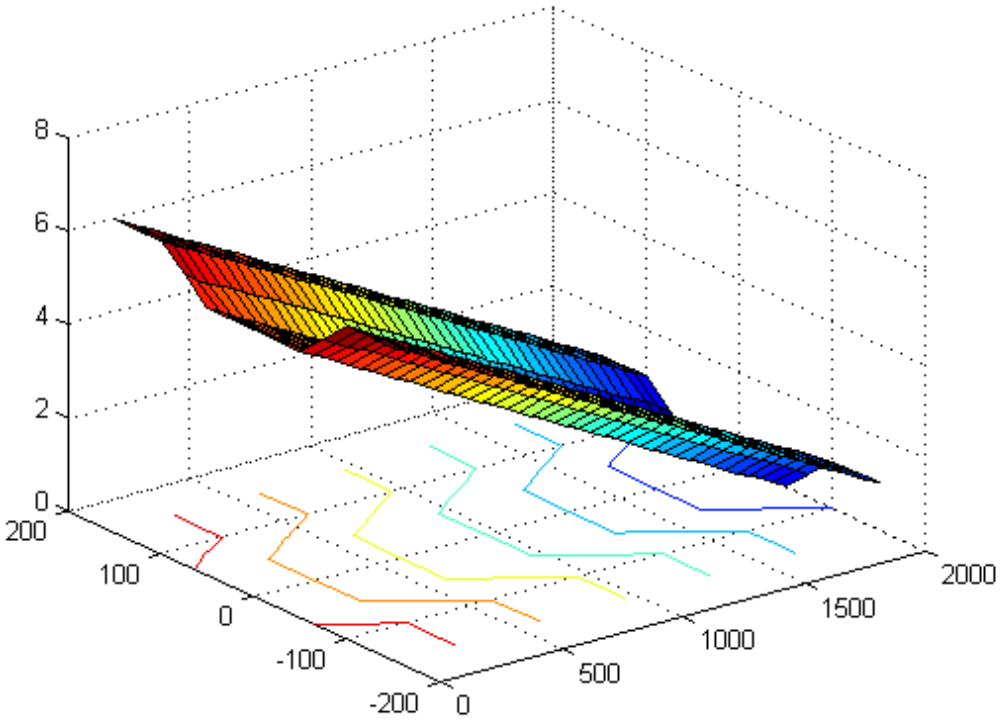


圖 20 10 分鐘後底床高程(非凝聚性沈滓，c=6000ppm)

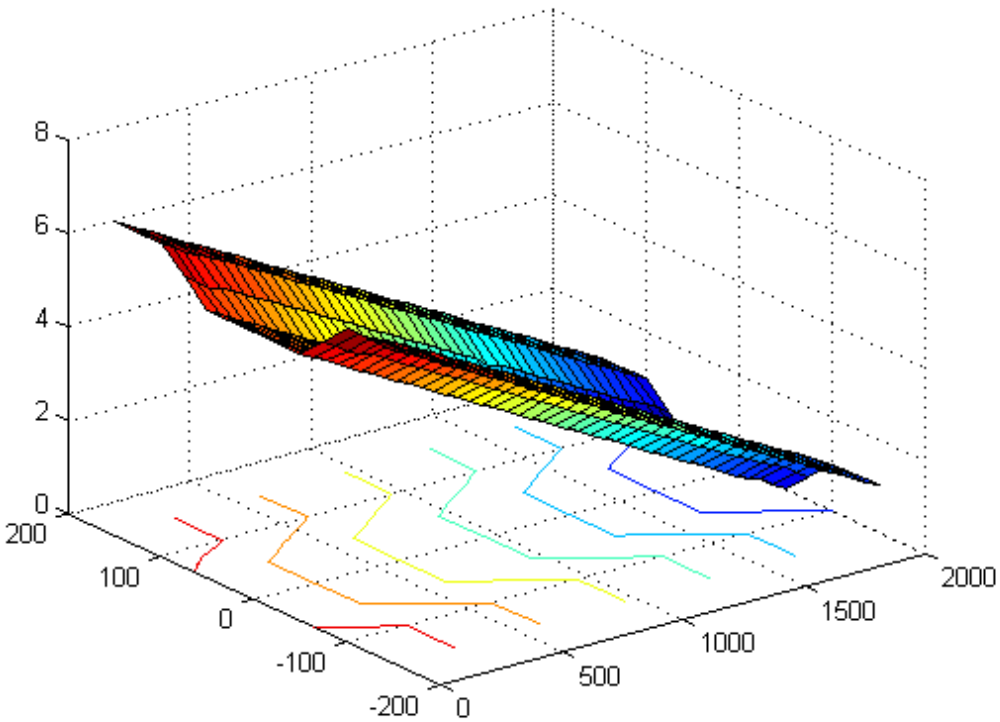


圖 21 20 分鐘後底床高程(非凝聚性沈滓，c=6000ppm)

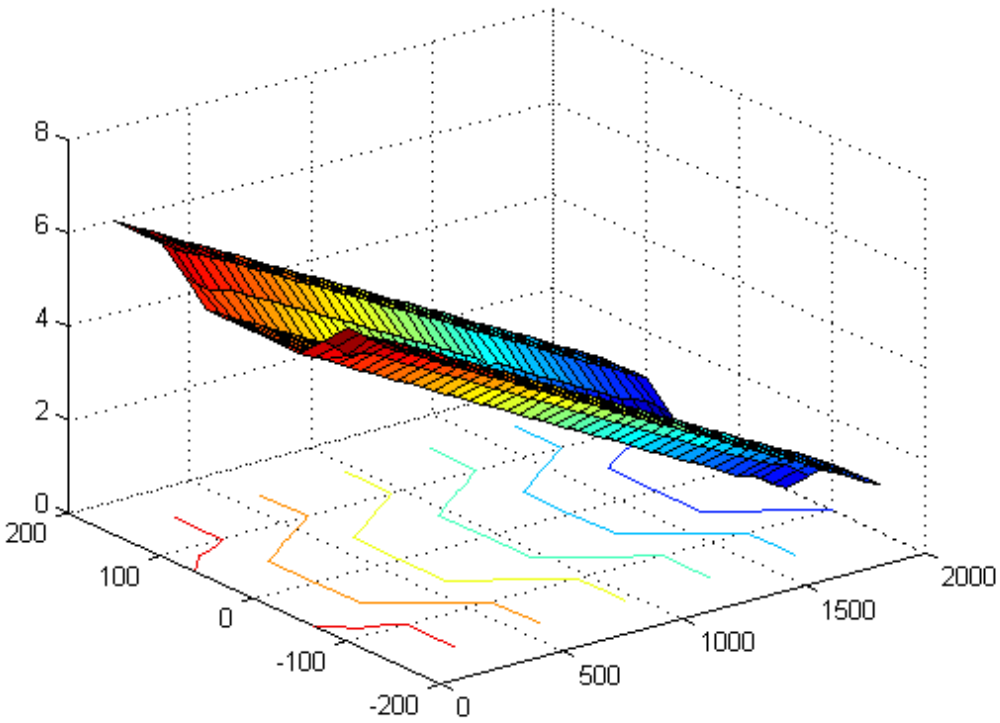


圖 22 30 分鐘後底床高程(非凝聚性沈滓，c=6000ppm)

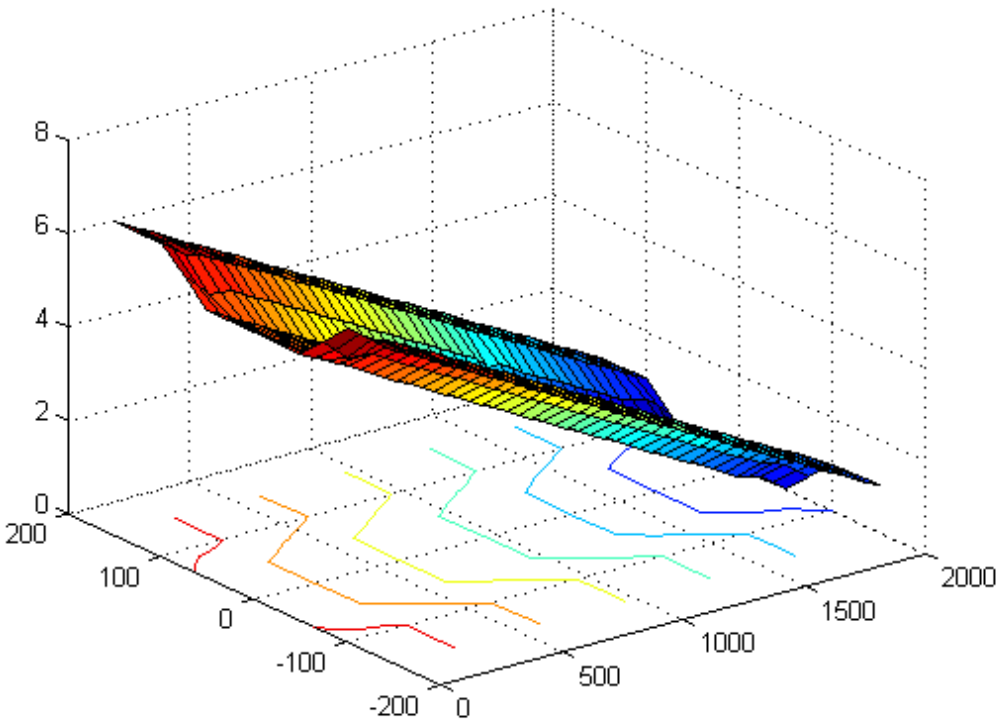


圖 23 40 分鐘後底床高程(非凝聚性沈滓，c=6000ppm)

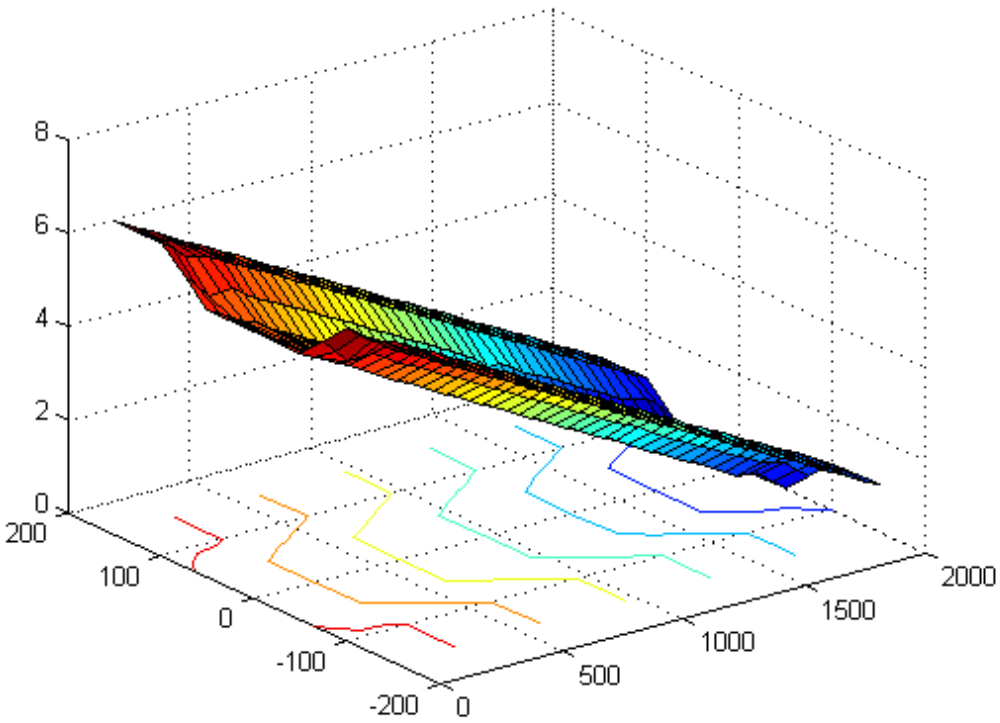


圖 24 50 分鐘後底床高程(非凝聚性沈滓，c=6000ppm)

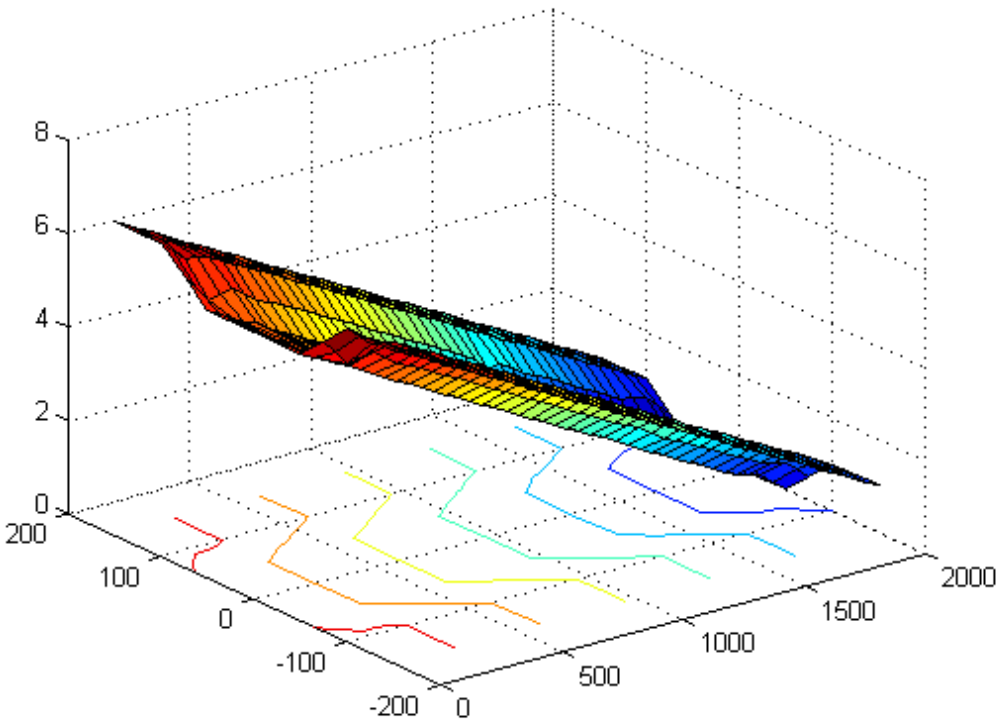


圖 25 60 分鐘後底床高程(非凝聚性沈滓，c=6000ppm)

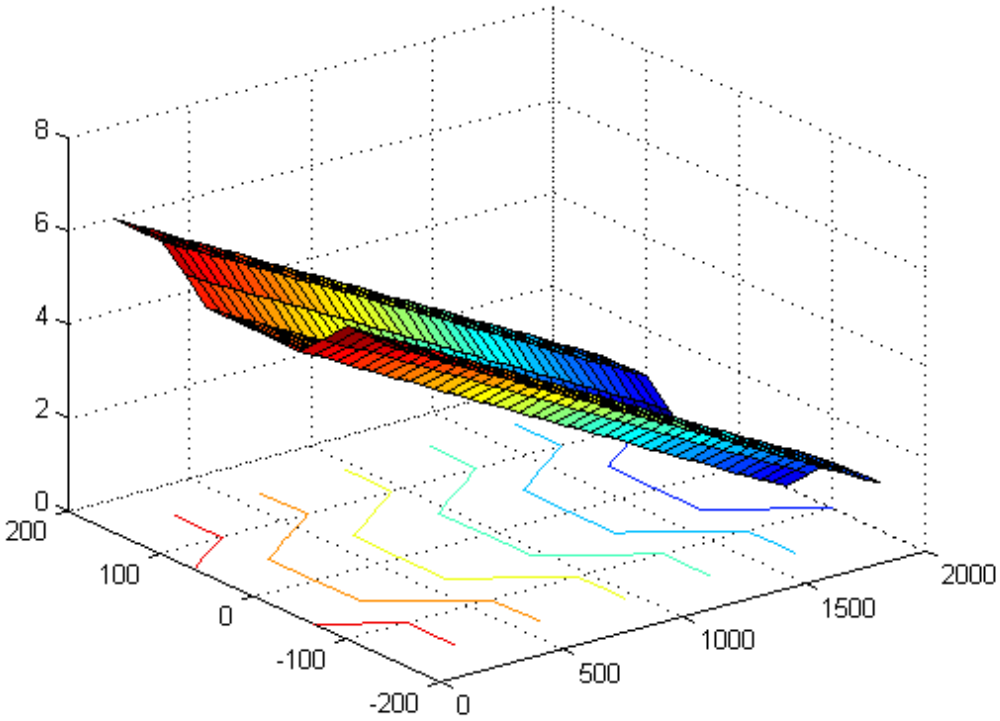


圖 26 10 分鐘後底床高程(非凝聚性沈滓，d=0.2mm)

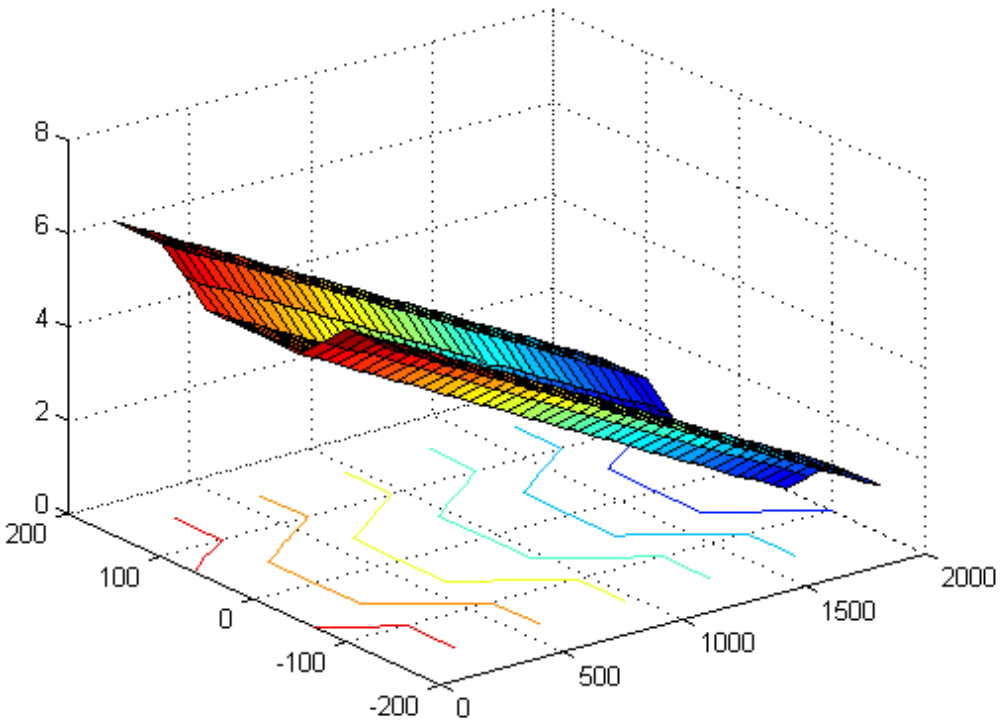


圖 27 20 分鐘後底床高程(非凝聚性沈滓，d=0.2mm)

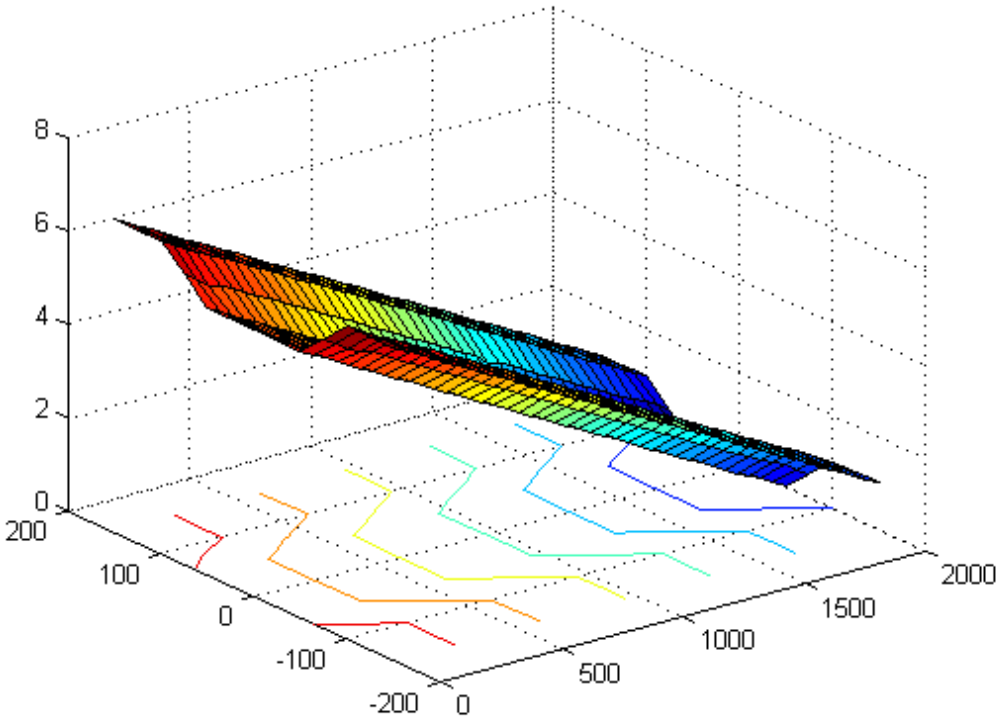


圖 28 30 分鐘後底床高程(非凝聚性沈滓，d=0.2mm)

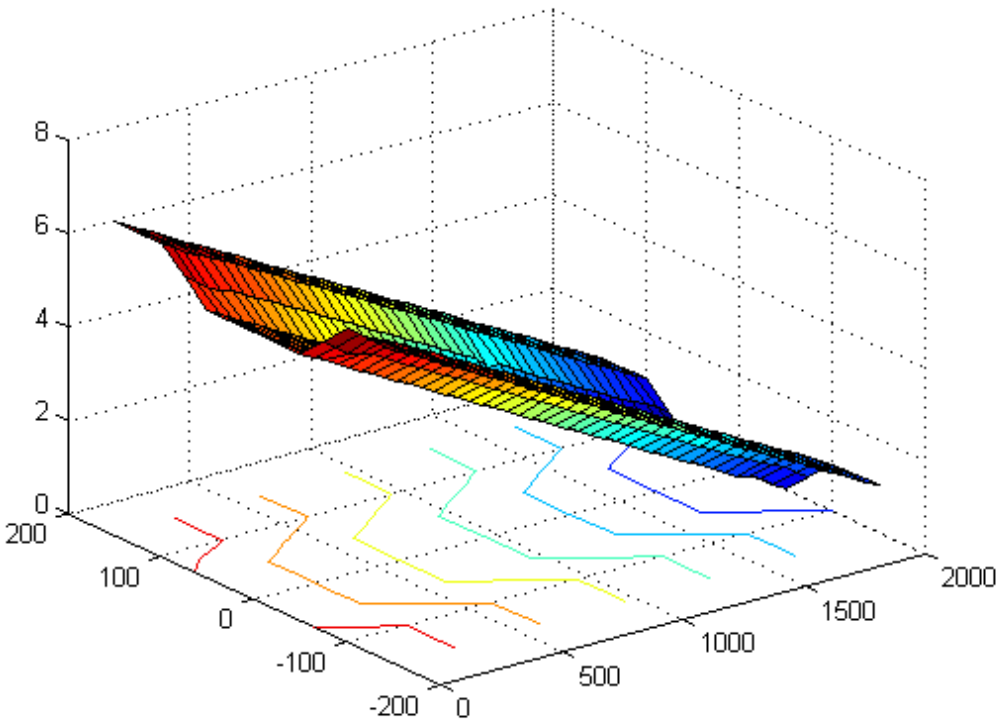


圖 29 40 分鐘後底床高程(非凝聚性沈滓，d=0.2mm)

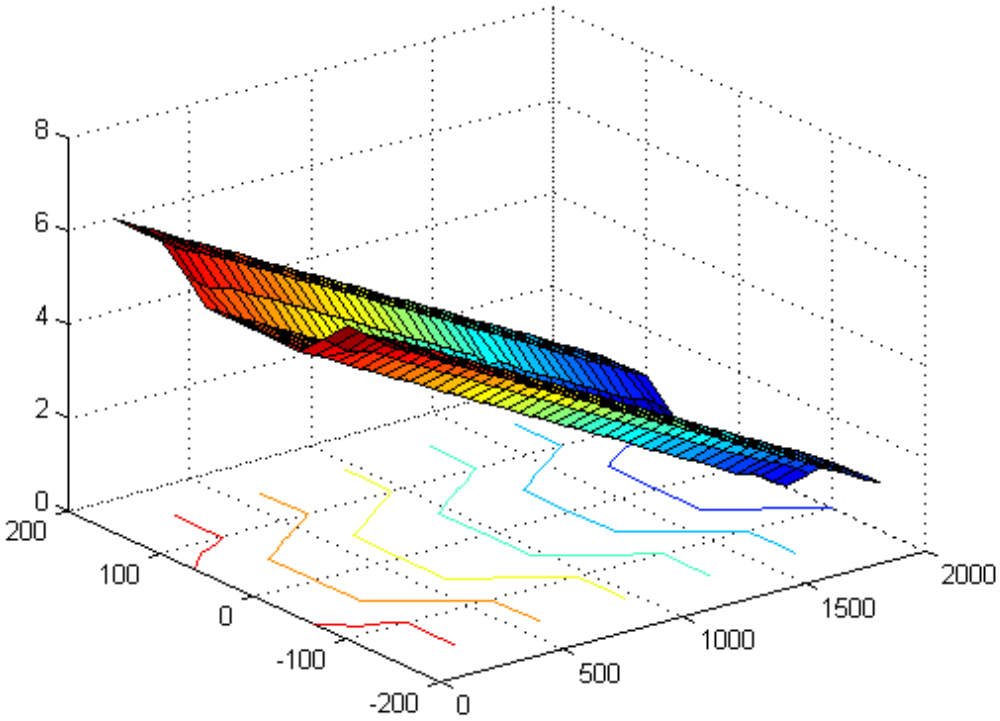


圖 30 50 分鐘後底床高程(非凝聚性沈滓，d=0.2mm)

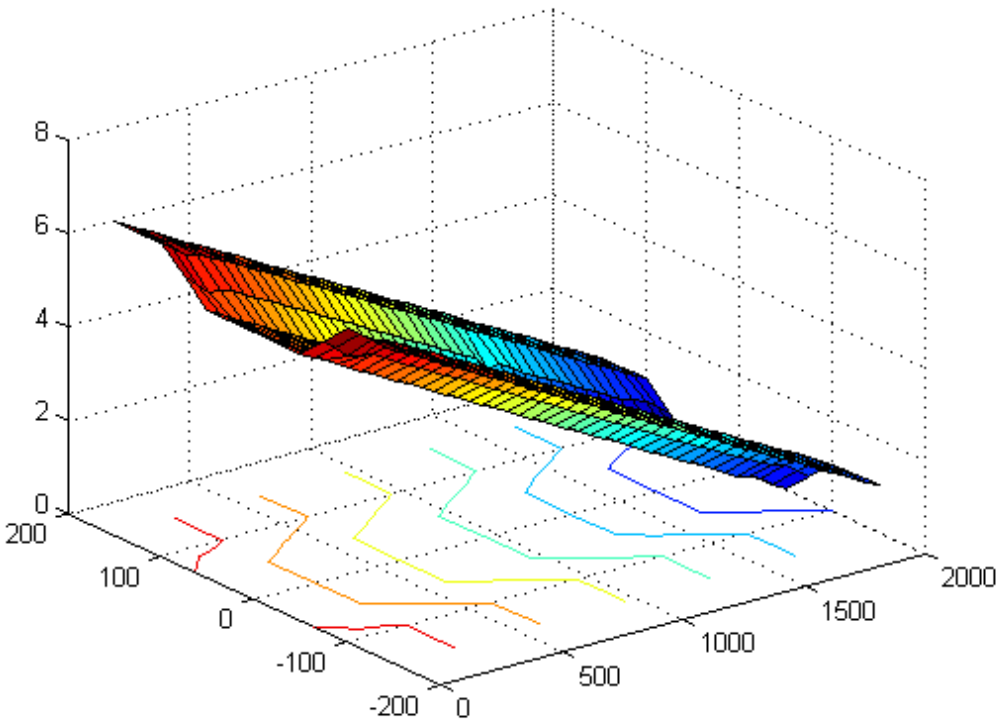


圖 31 60 分鐘後底床高程(非凝聚性沈滓，d=0.2mm)

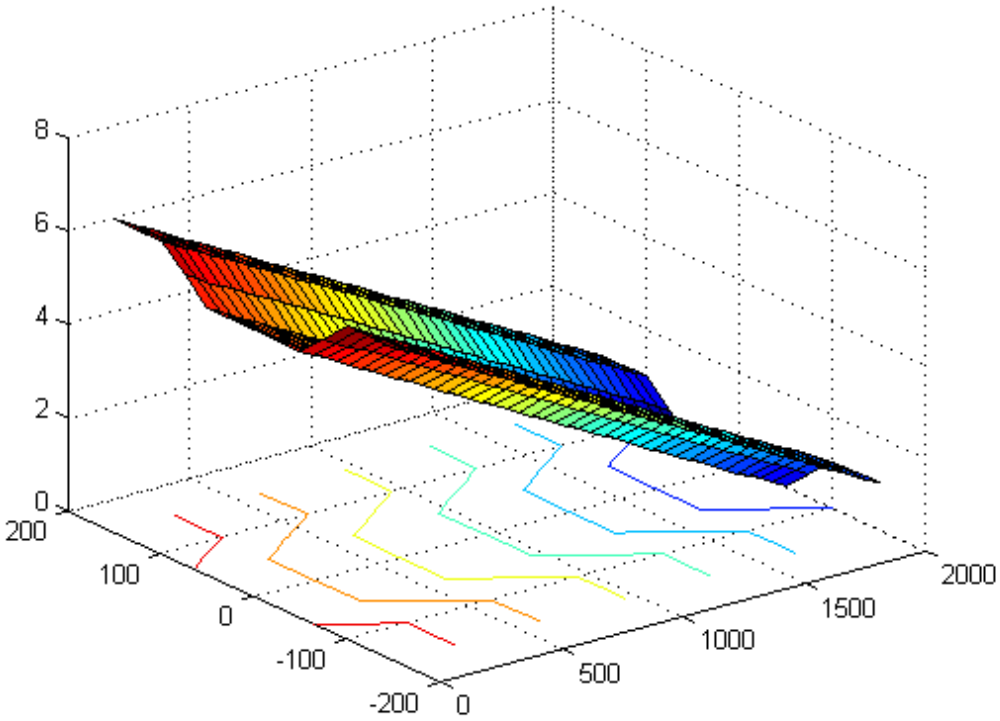


圖 32 10 分鐘後底床高程(非凝聚性沈滓，d=0.8mm)

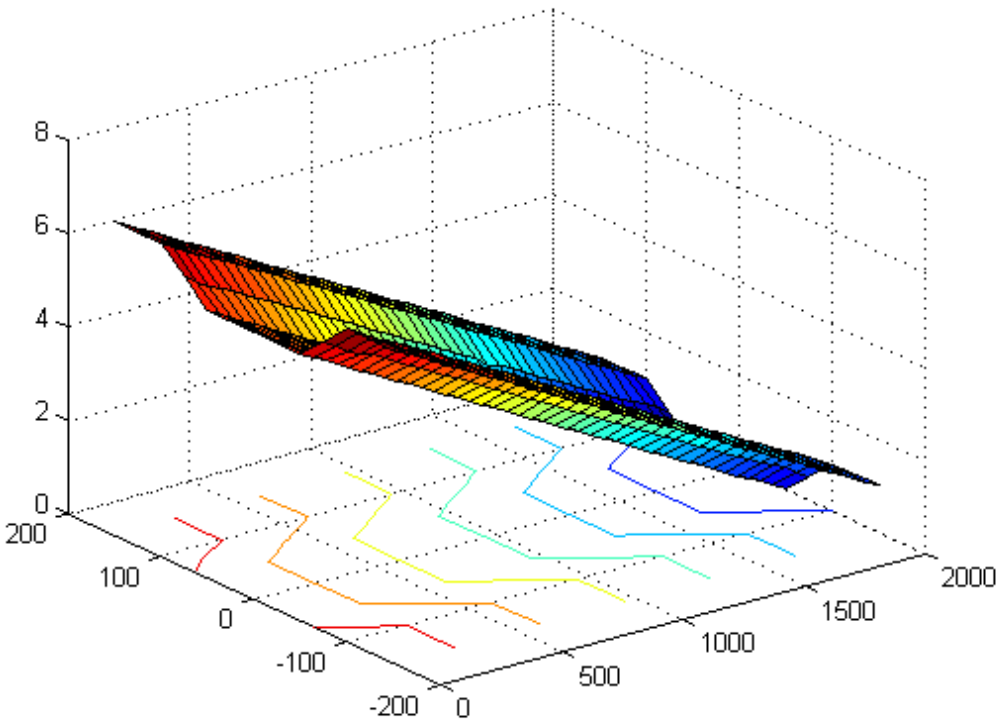


圖 33 20 分鐘後底床高程(非凝聚性沈滓，d=0.8mm)

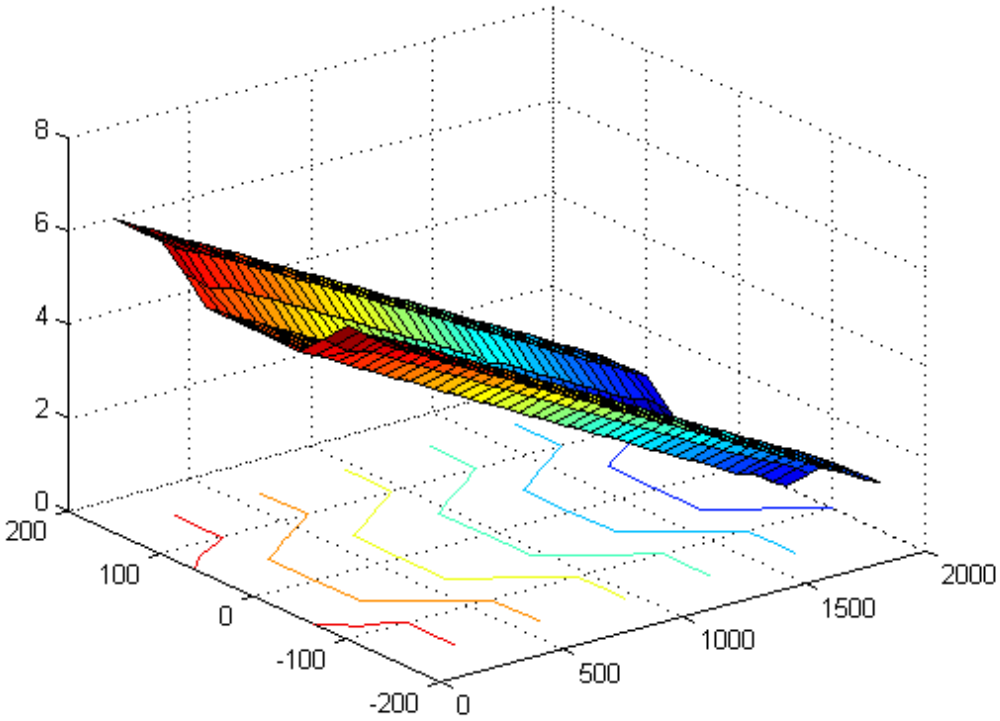


圖 34 30 分鐘後底床高程(非凝聚性沈滓，d=0.8mm)

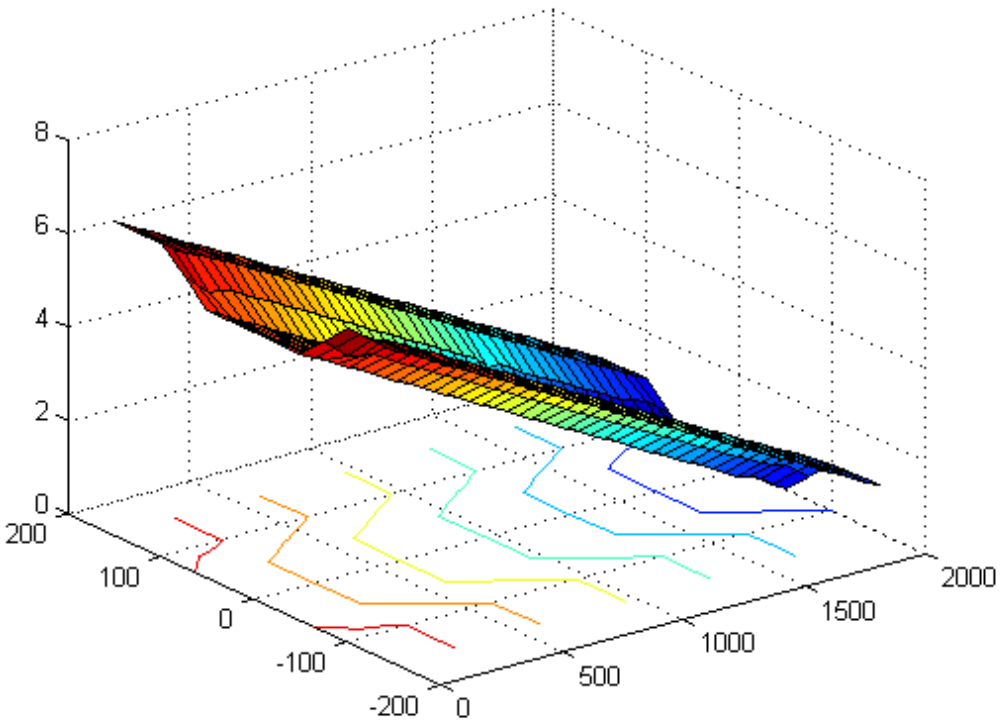


圖 35 40 分鐘後底床高程(非凝聚性沈滓，d=0.8mm)

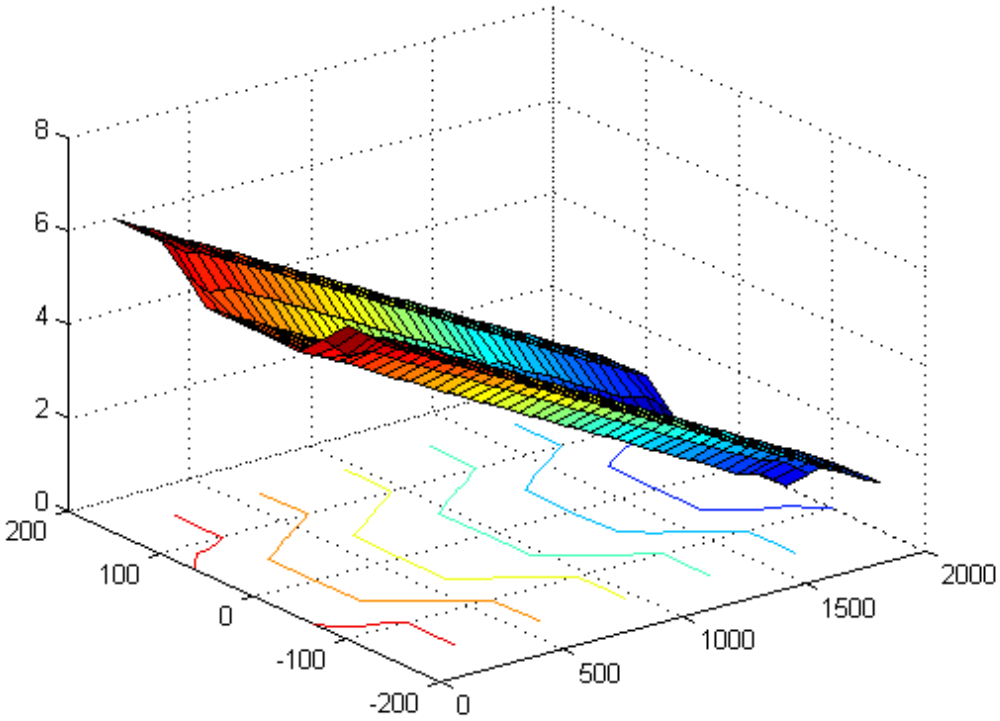


圖 36 50 分鐘後底床高程(非凝聚性沈滓，d=0.8mm)

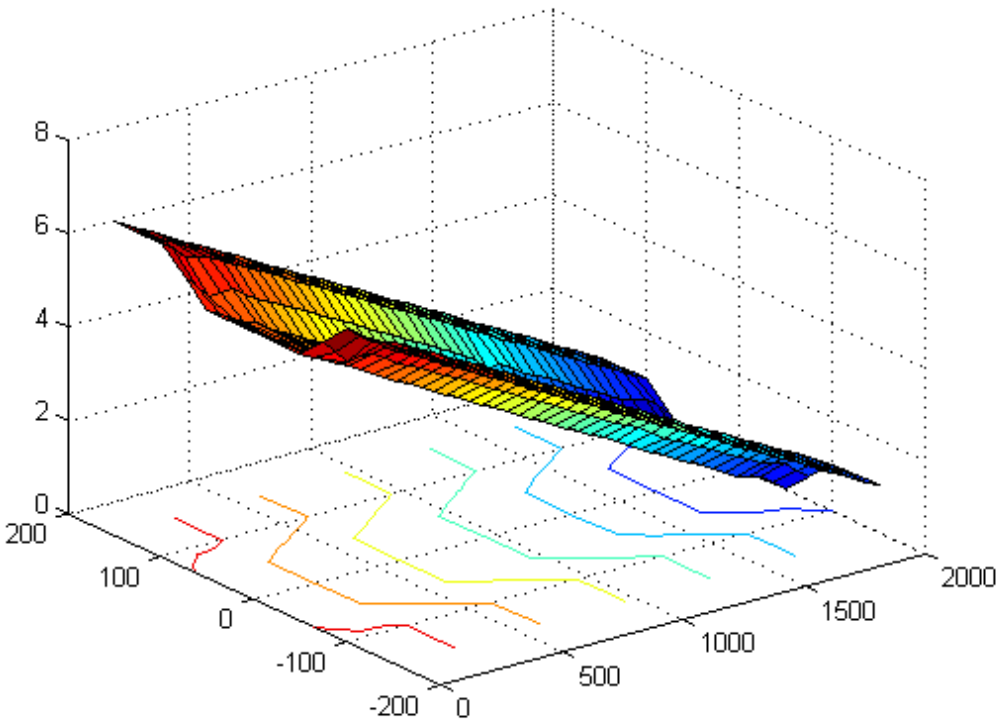


圖 37 60 分鐘後底床高程(非凝聚性沈滓，d=0.8mm)

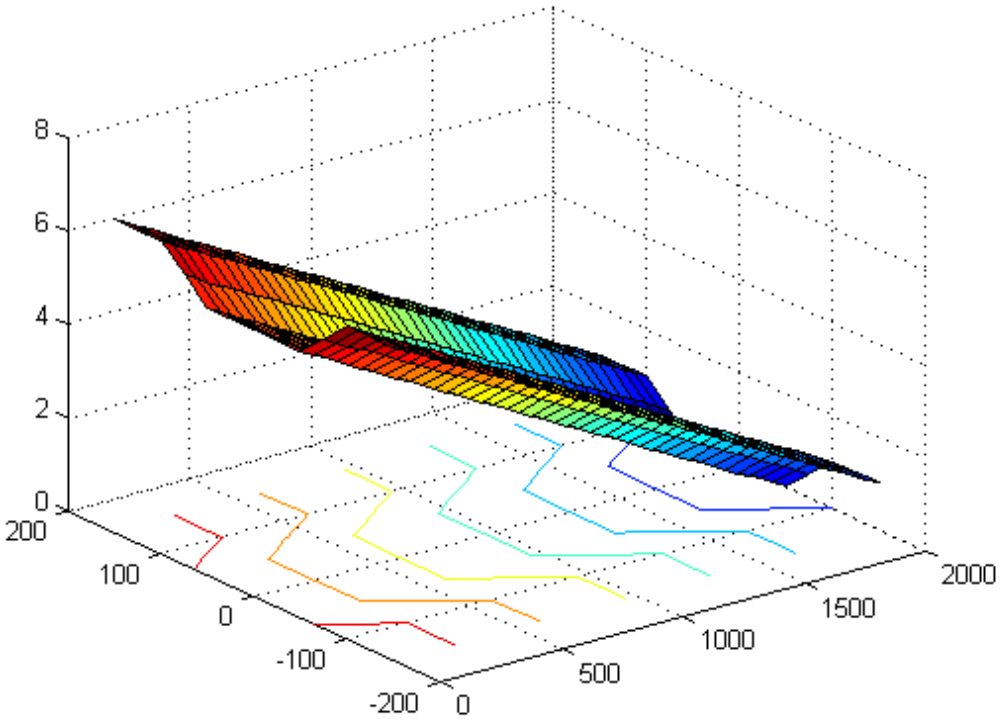


圖 38 10 分鐘後底床高程(非凝聚性沈滓，q=0.95cms/m)

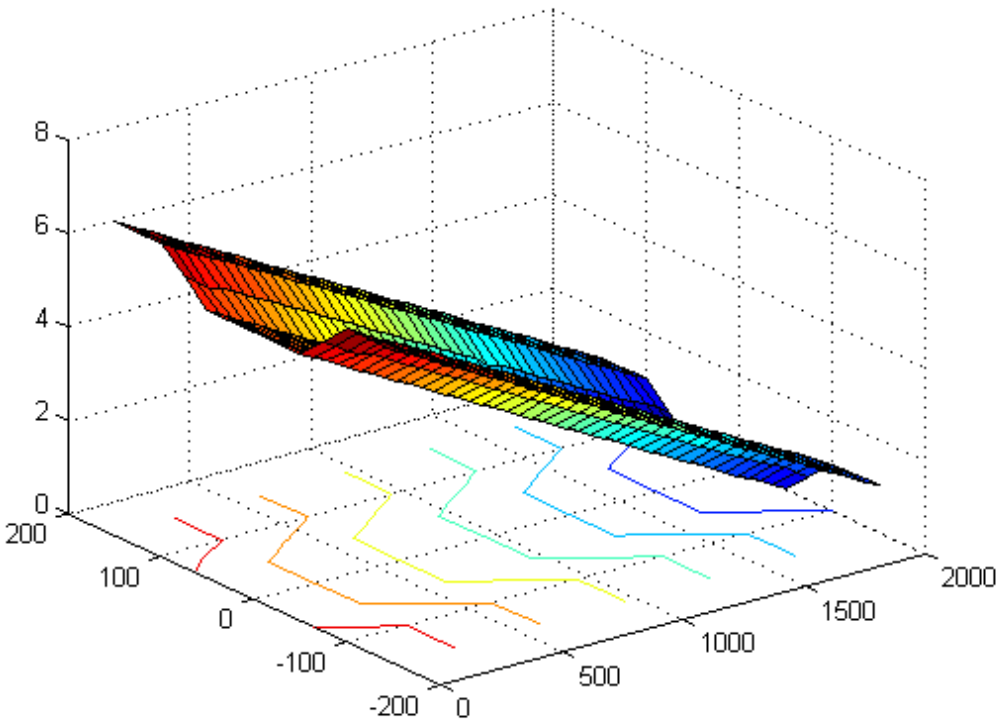


圖 39 20 分鐘後底床高程(非凝聚性沈滓，q=0.95cms/m)

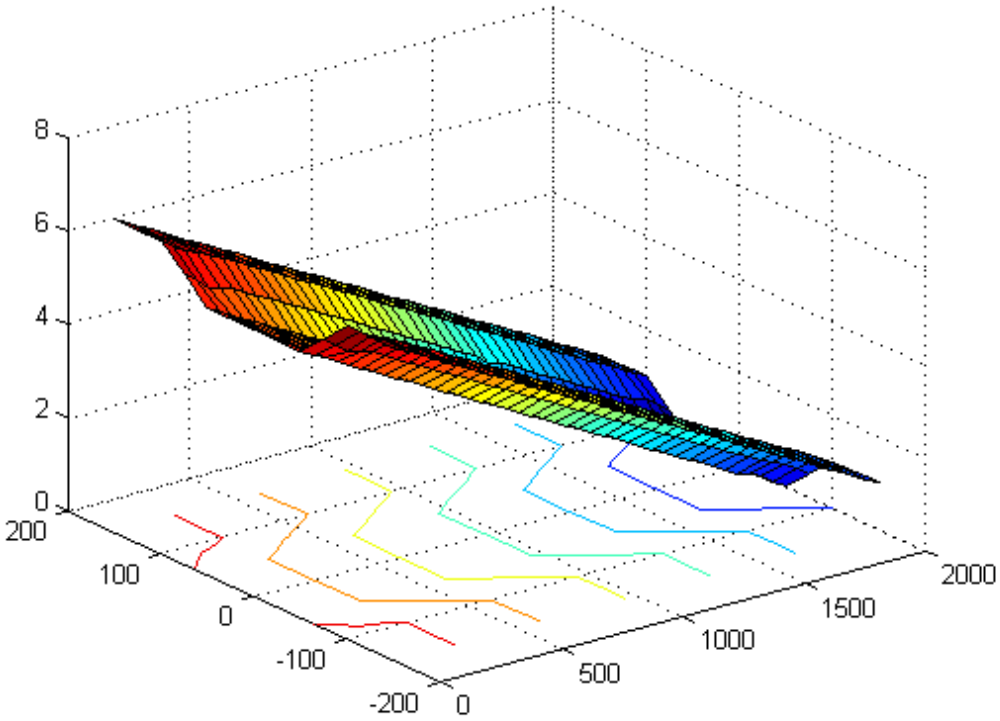


圖 40 30 分鐘後底床高程(非凝聚性沈滓，q=0.95cms/m)

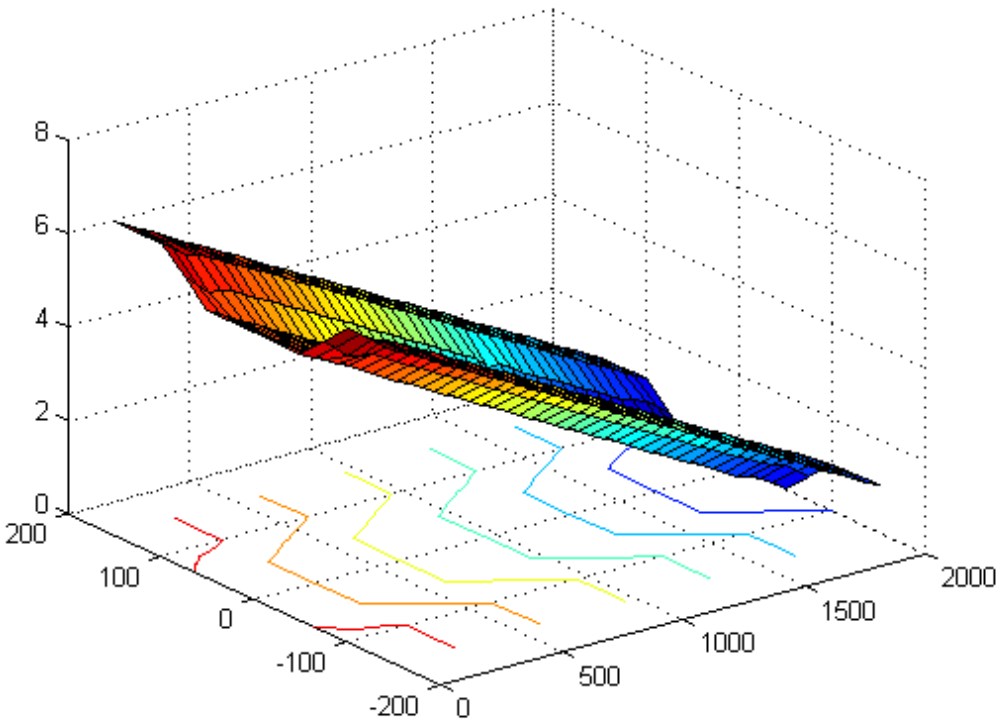


圖 41 40 分鐘後底床高程(非凝聚性沈滓，q=0.95cms/m)

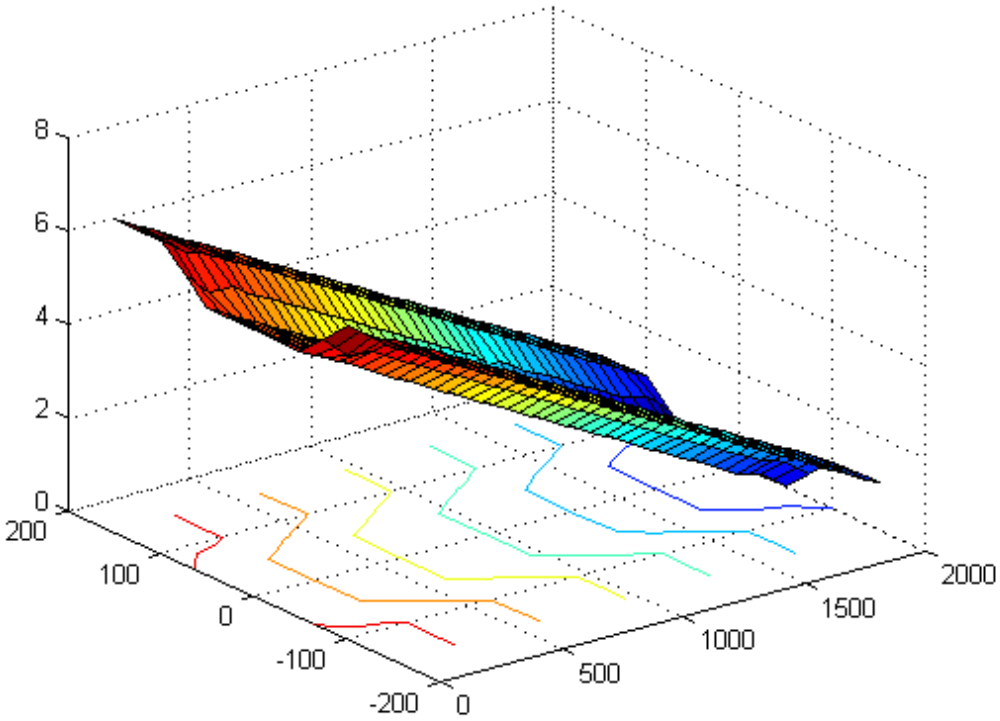


圖 42 50 分鐘後底床高程(非凝聚性沈滓，q=0.95cms/m)

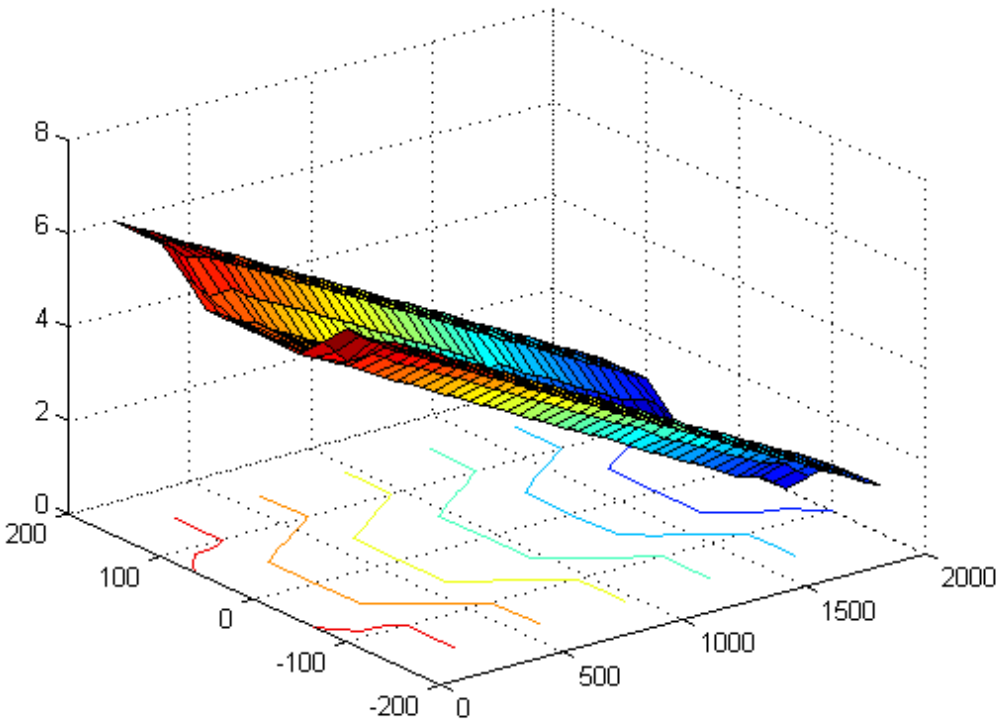


圖 43 60 分鐘後底床高程(非凝聚性沈滓，q=0.95cms/m)

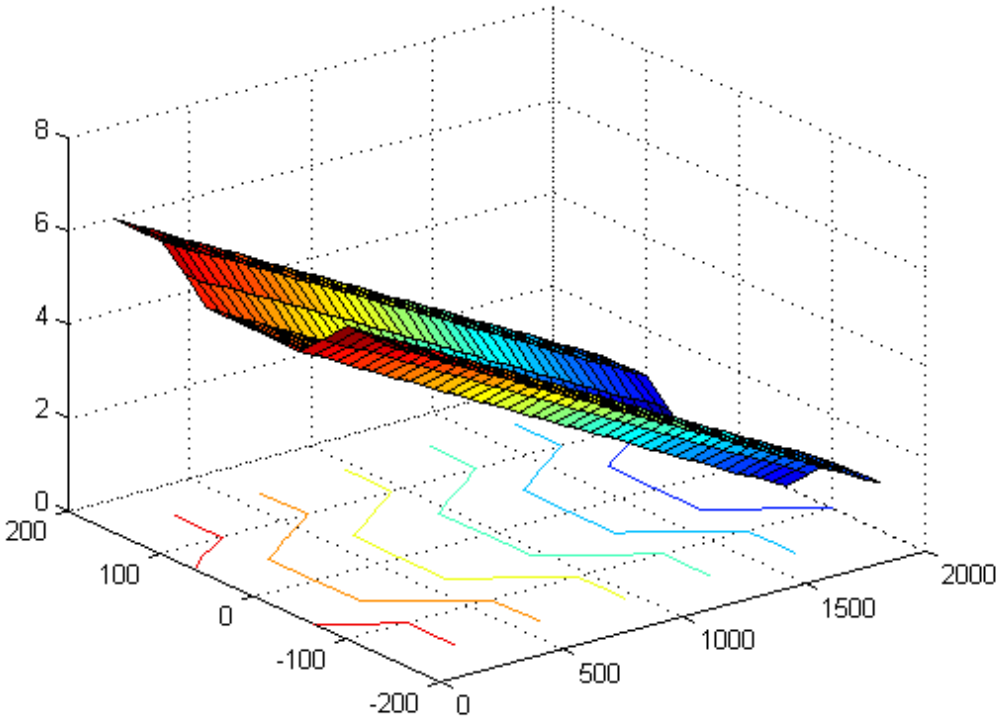


圖 44 10 分鐘後底床高程(非凝聚性沈滓，q=1.05cms/m)

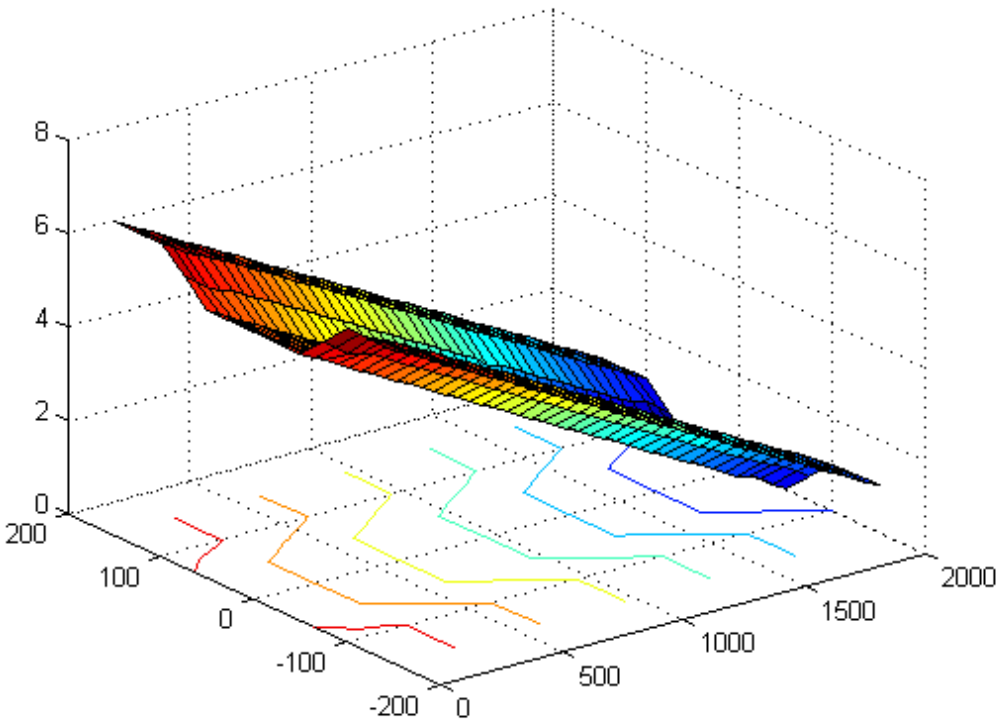


圖 45 20 分鐘後底床高程(非凝聚性沈滓，q=1.05cms/m)

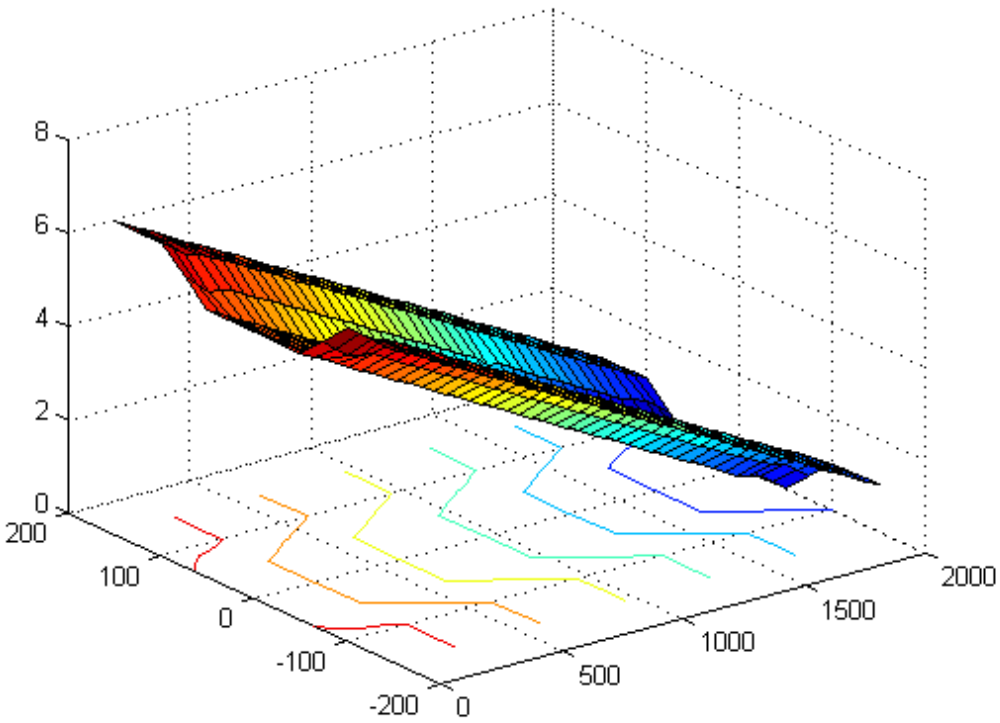


圖 46 30 分鐘後底床高程(非凝聚性沈滓，q=1.05cms/m)

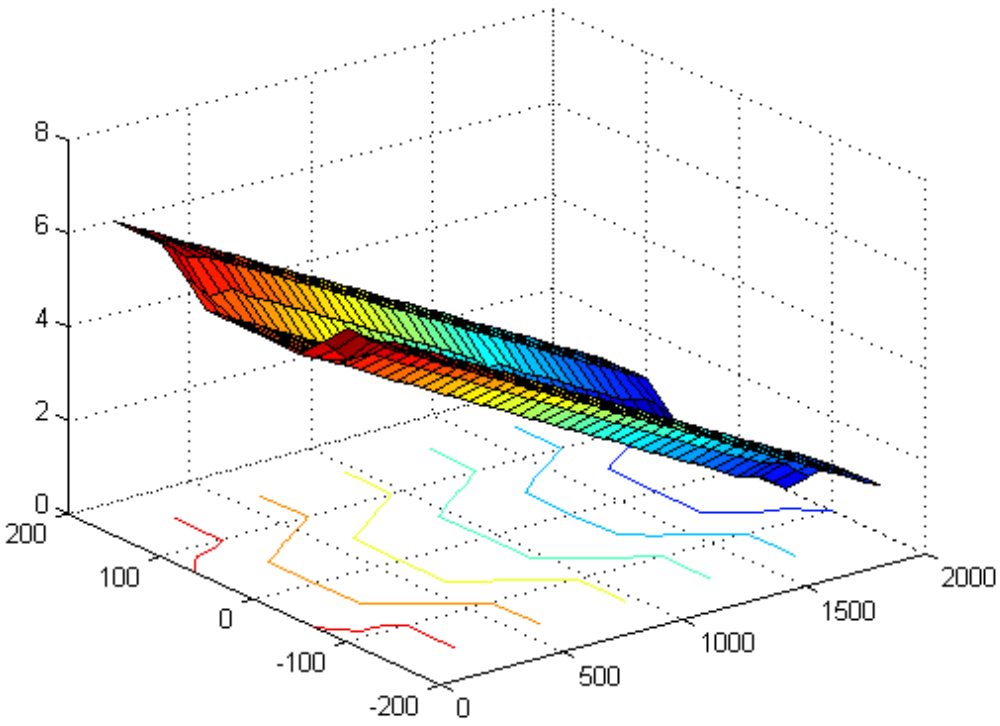


圖 47 40 分鐘後底床高程(非凝聚性沈滓，q=1.05cms/m)

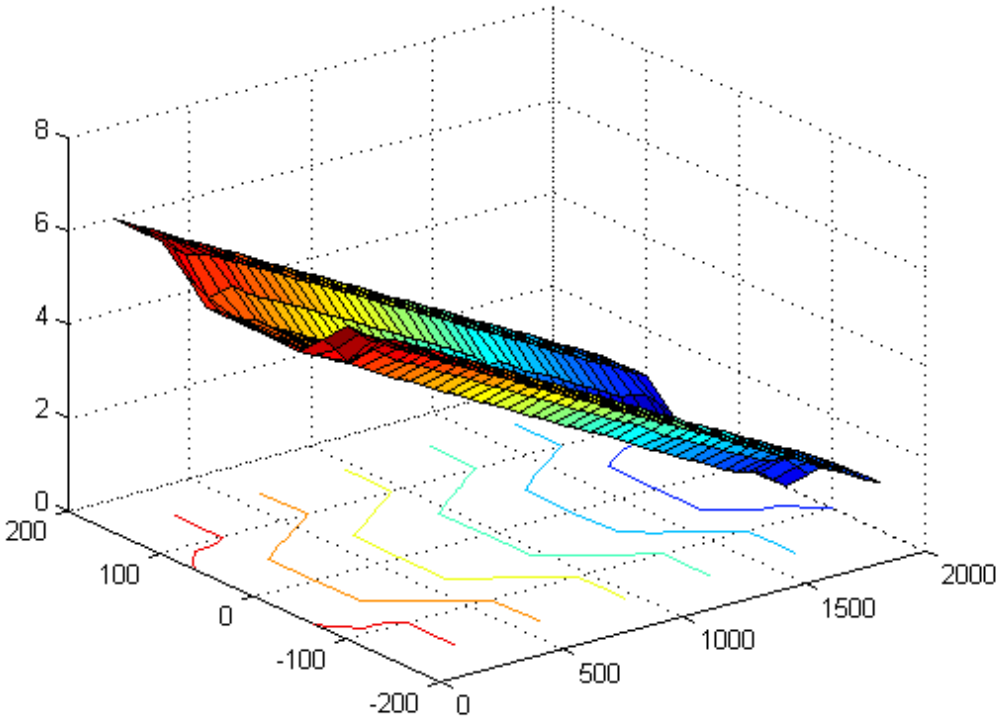


圖 48 50 分鐘後底床高程(非凝聚性沈滓，q=1.05cms/m)

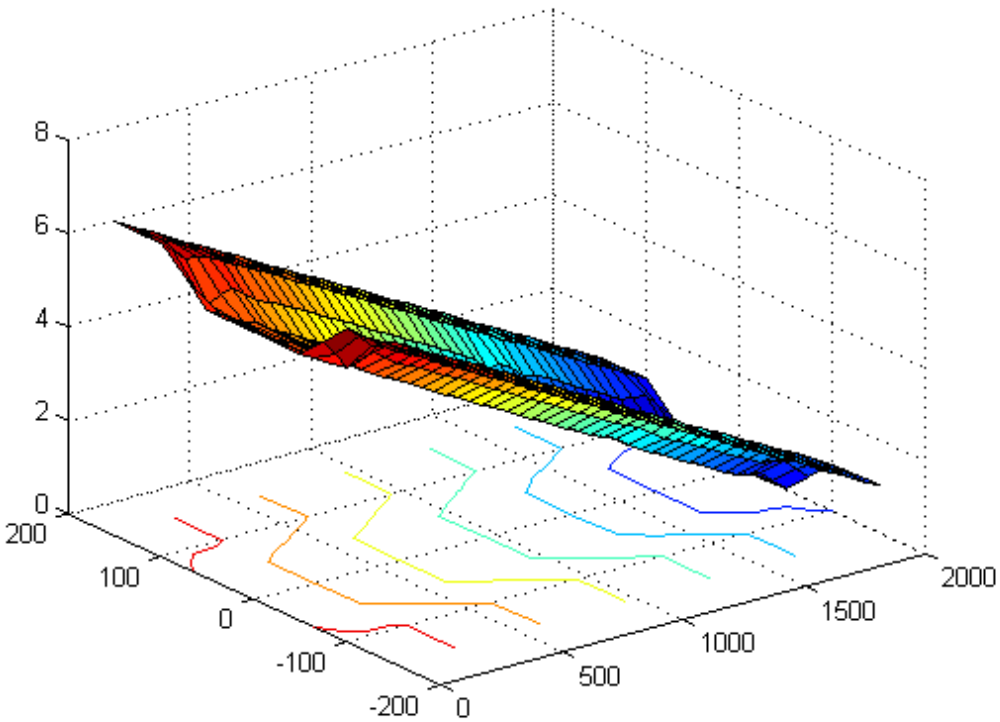


圖 49 60 分鐘後底床高程(非凝聚性沈滓，q=1.05cms/m)

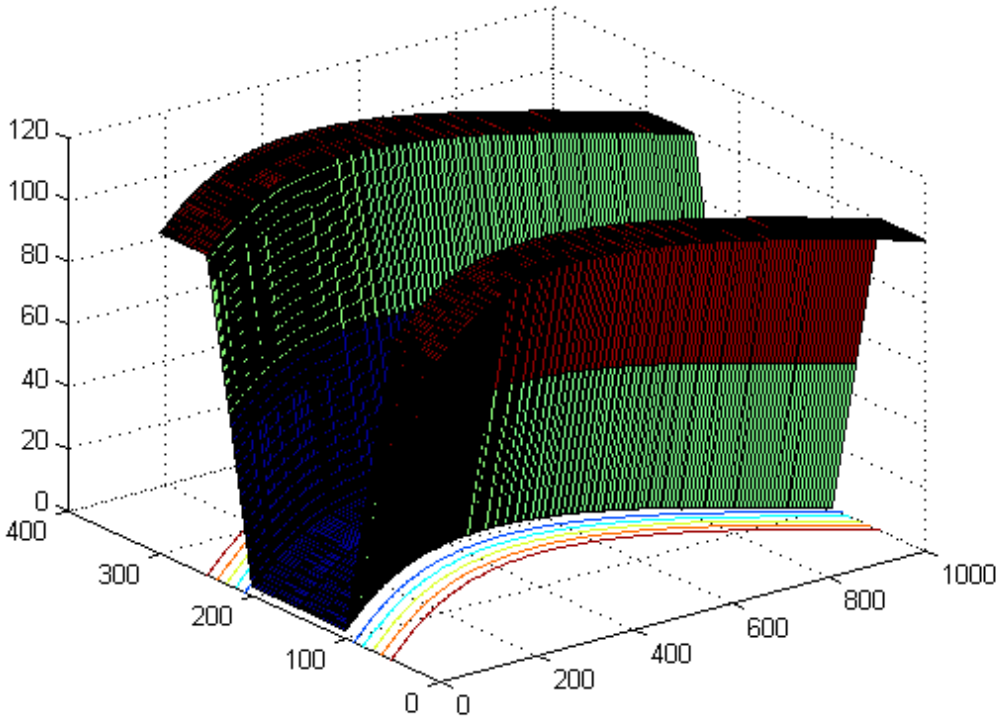


圖 50 原始底床高程

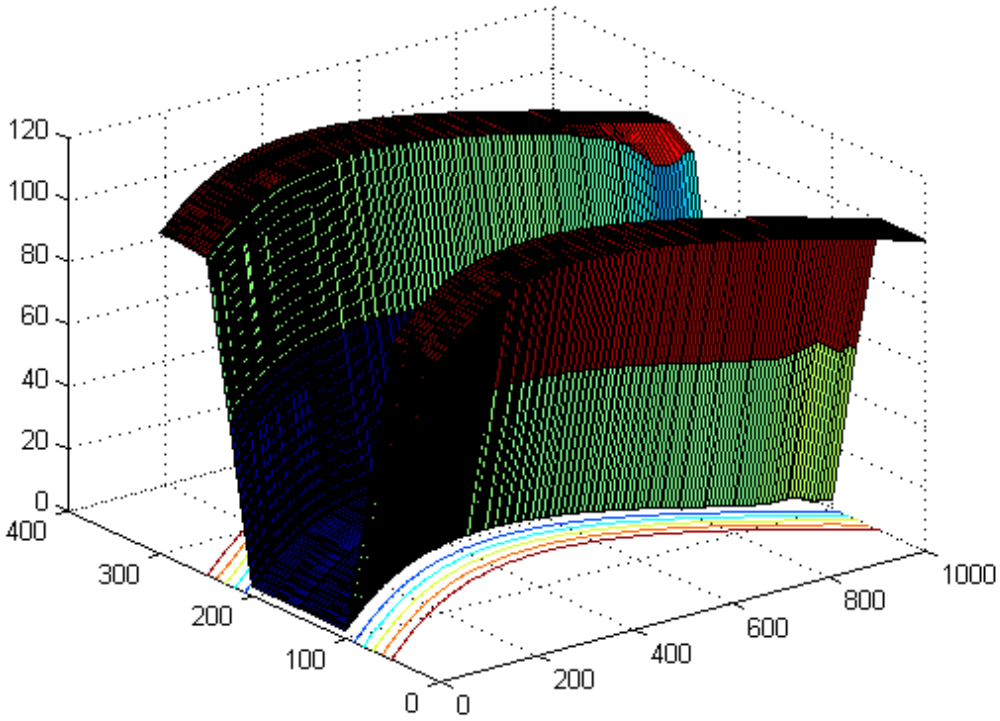


圖 51 10 分鐘後底床高程(非凝聚性沈滓)

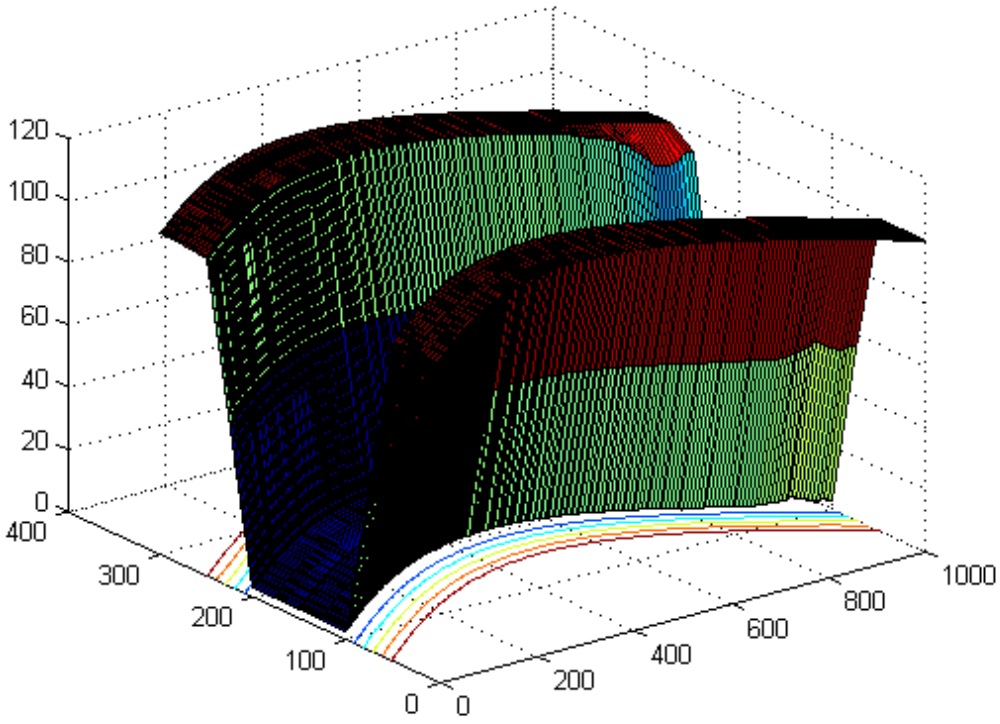


圖 52 20 分鐘後底床高程(非凝聚性沈滓)

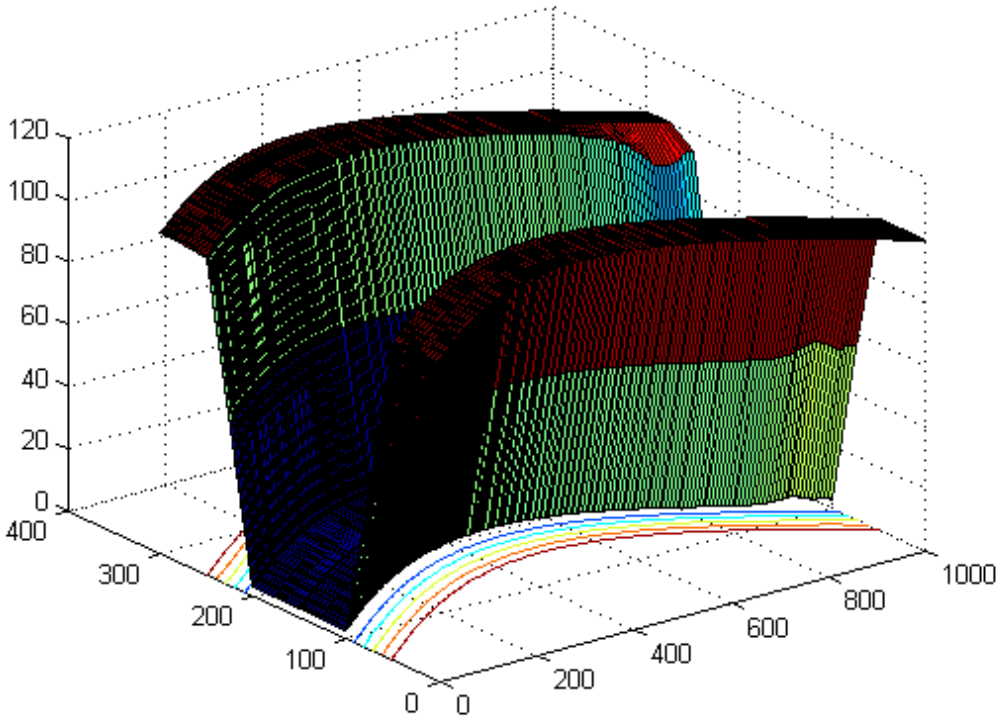


圖 53 30 分鐘後底床高程(非凝聚性沈滓)

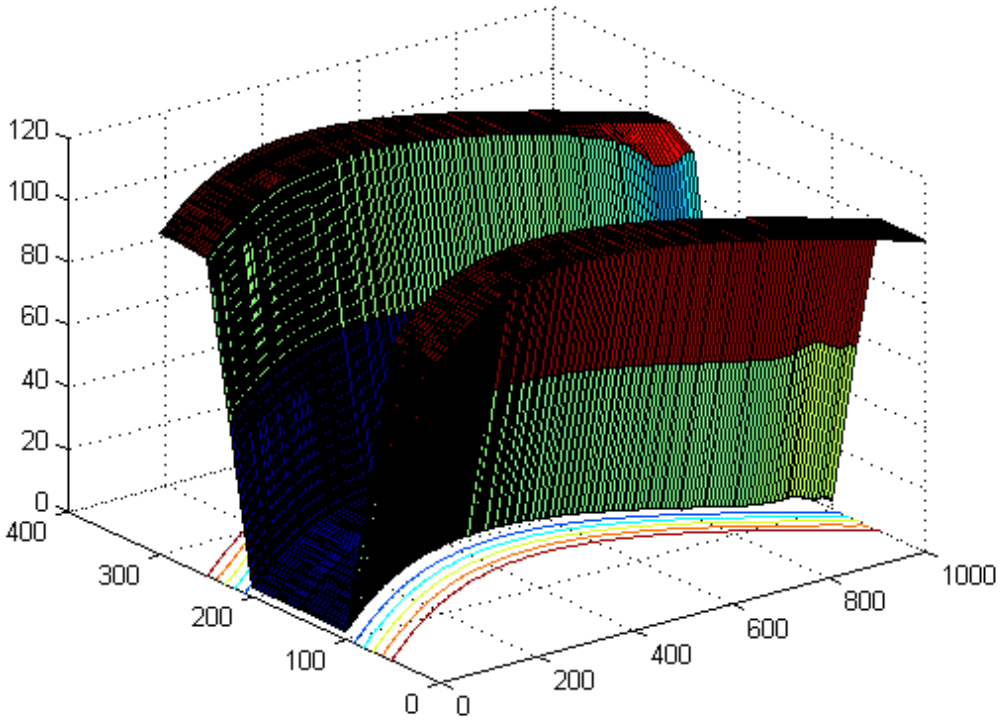


圖 54 40 分鐘後底床高程(非凝聚性沈滓)

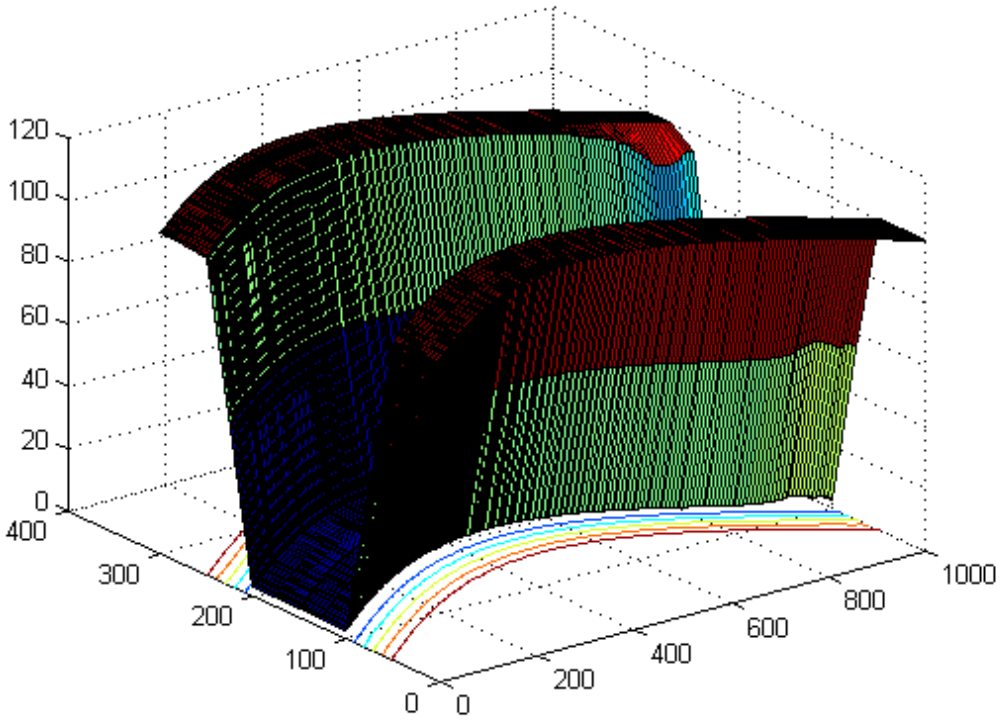


圖 55 50 分鐘後底床高程(非凝聚性沈滓)

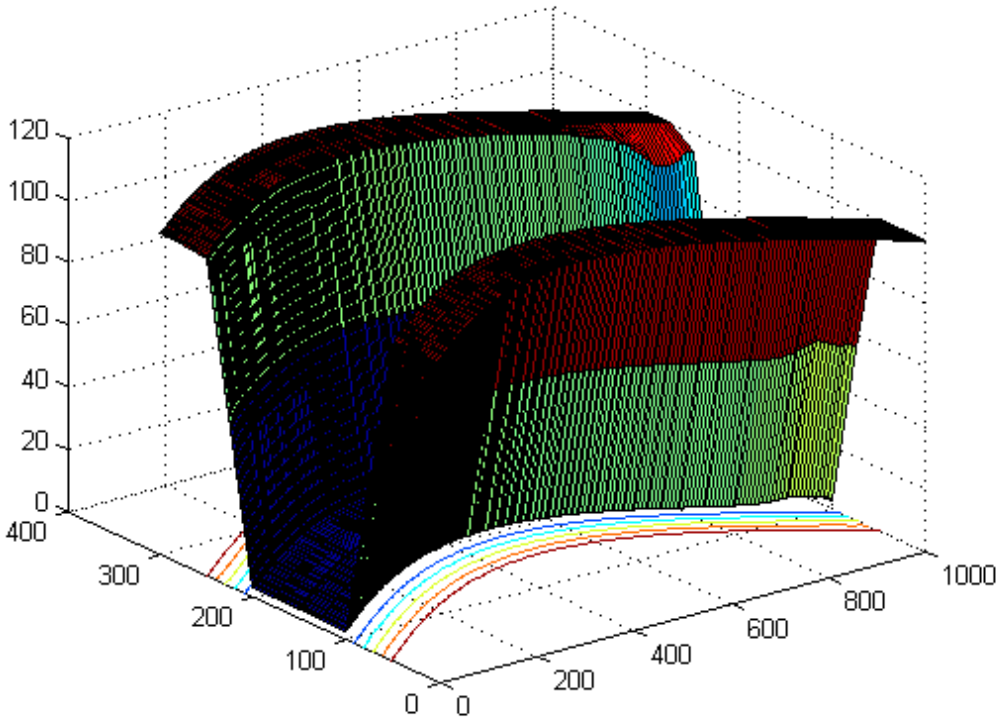


圖 56 60 分鐘後底床高程(非凝聚性沈滓)

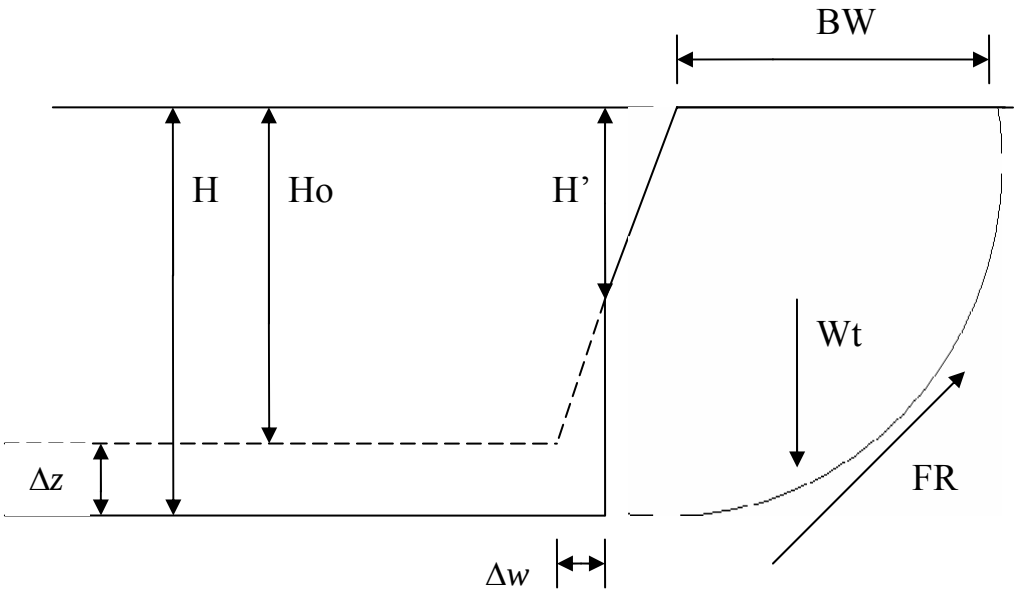


圖 57 岸壁幾何形狀示意圖（圓弧崩坍）

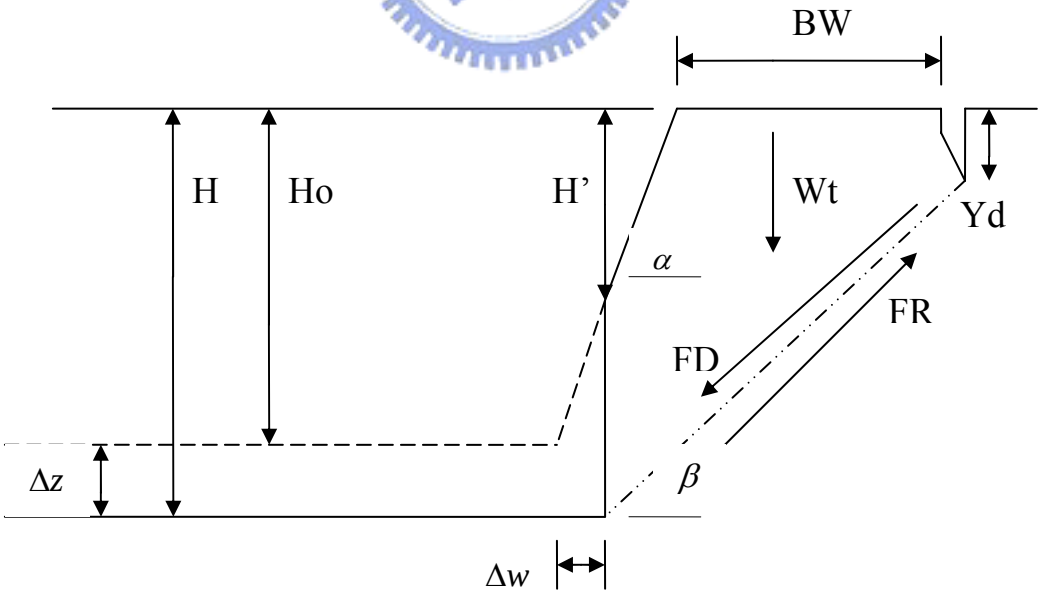


圖 58 岸壁幾何形狀示意圖（平面崩坍）

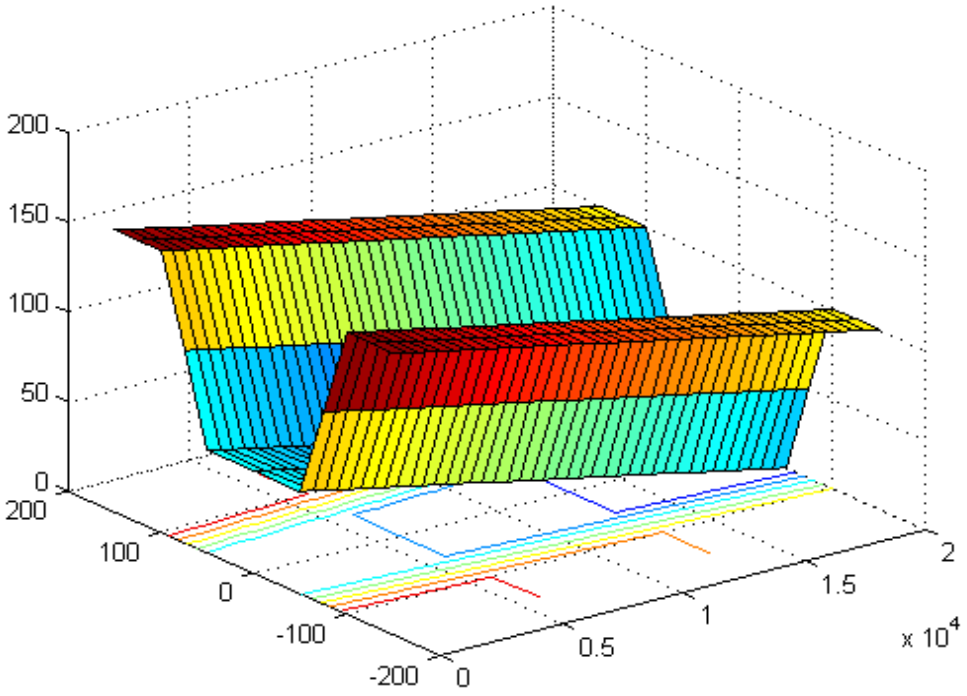


圖 59 原始底床高程

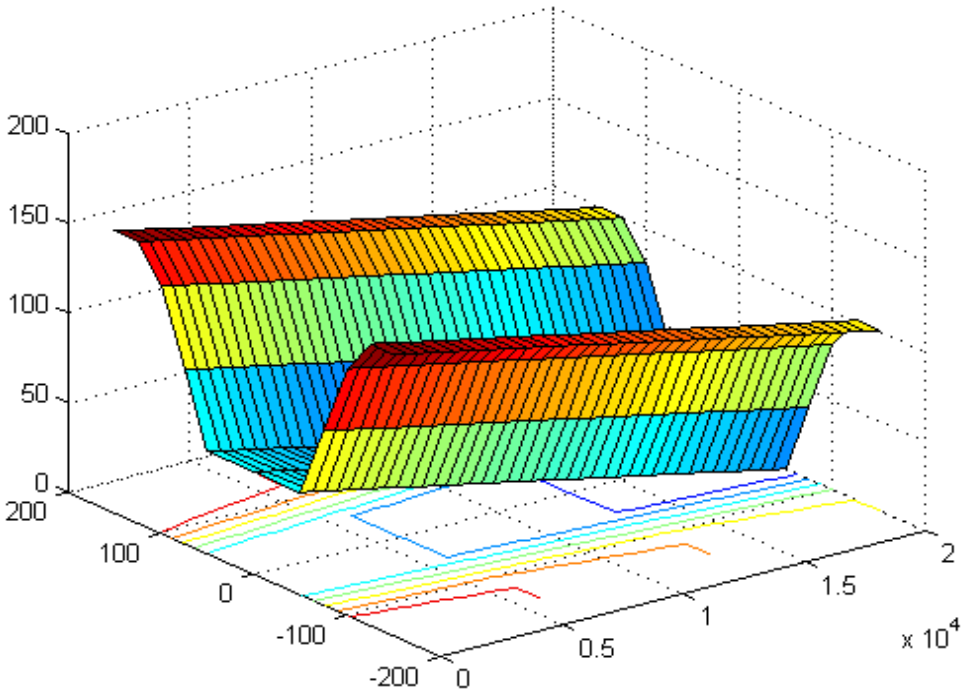


圖 60 10 分鐘後底床高程（圓弧崩坍機制）

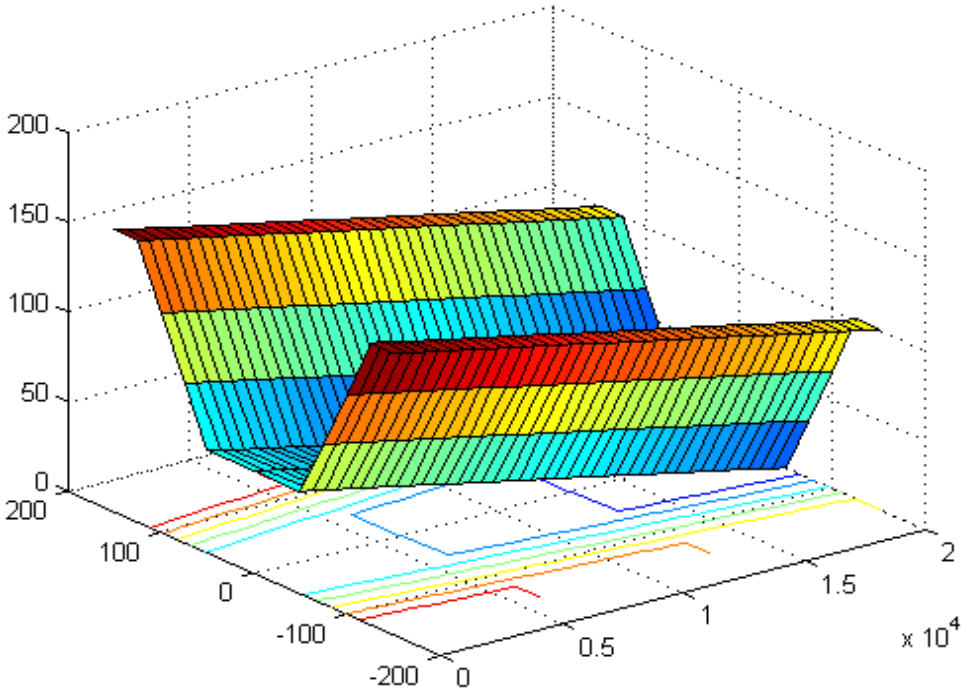


圖 61 20 分鐘後底床高程（圓弧崩坍機制）

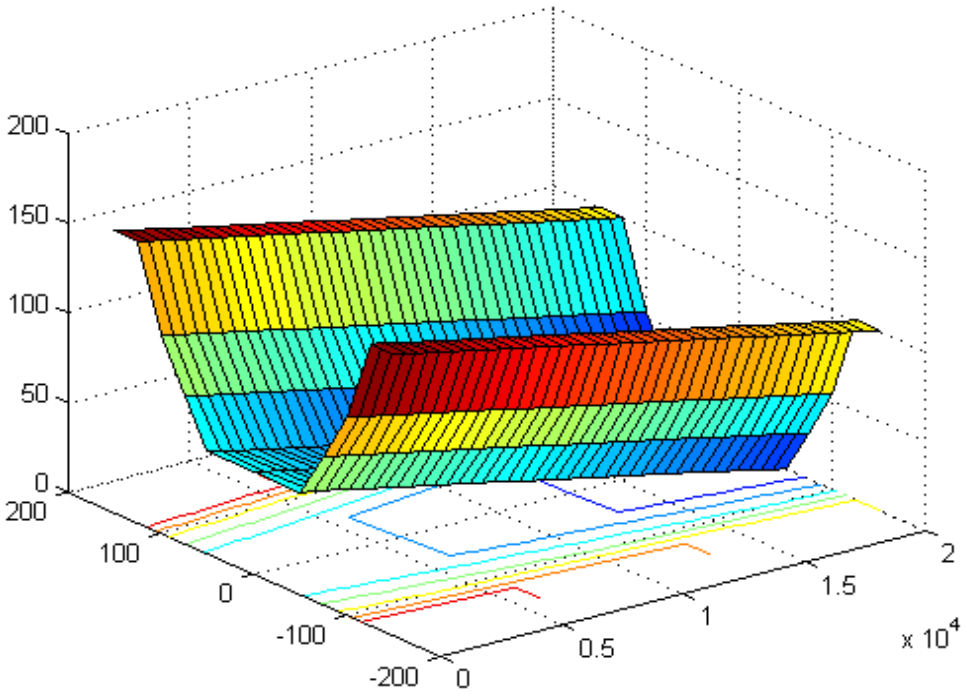


圖 62 30 分鐘後底床高程（圓弧崩坍機制）

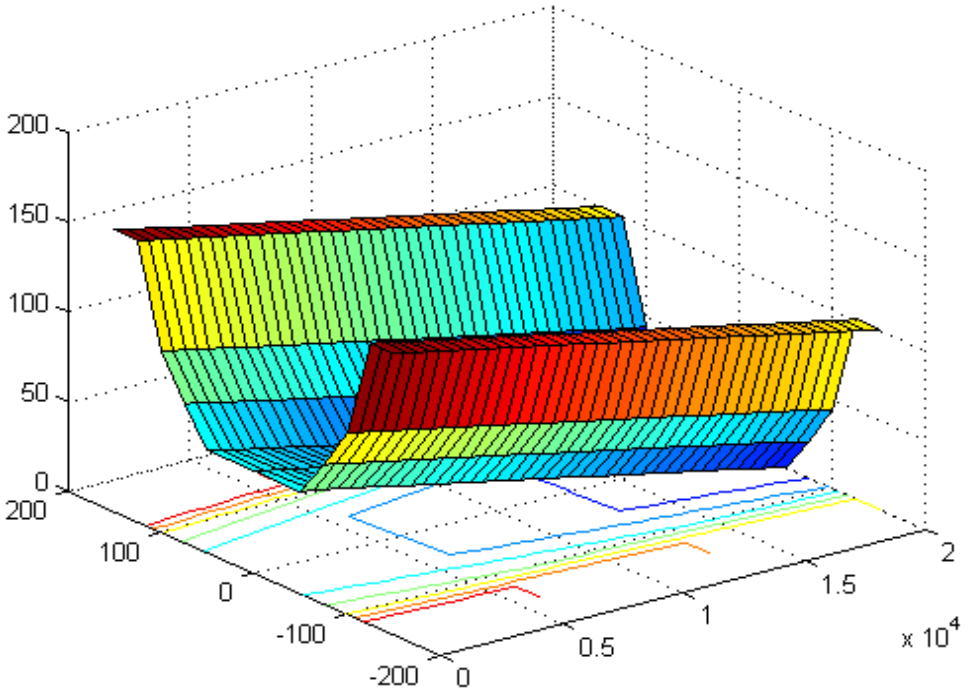


圖 63 40 分鐘後底床高程（圓弧崩坍機制）

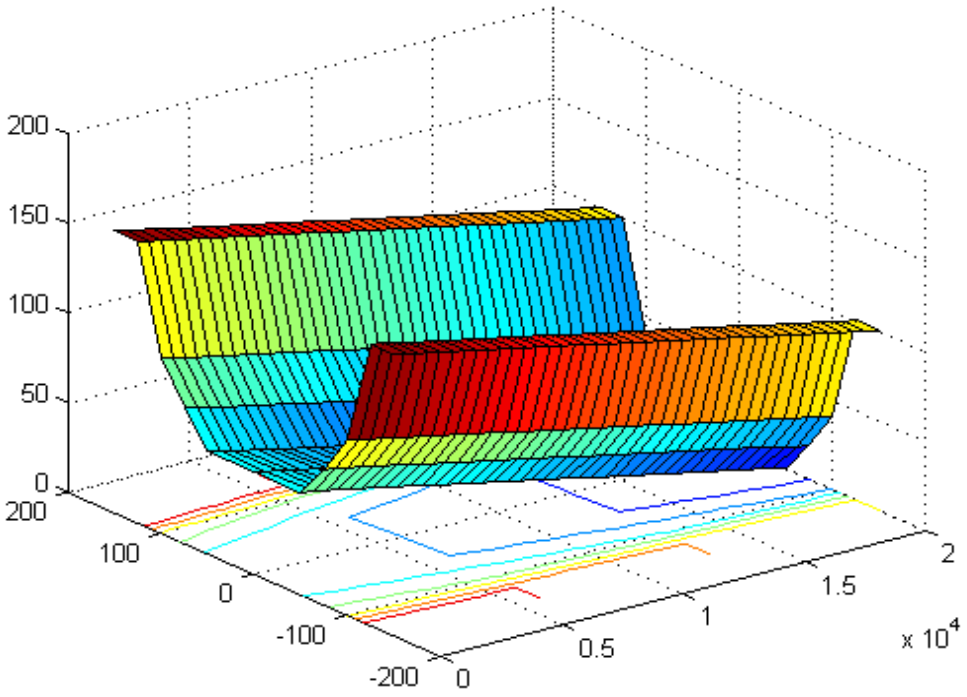


圖 64 50 分鐘後底床高程（圓弧崩坍機制）

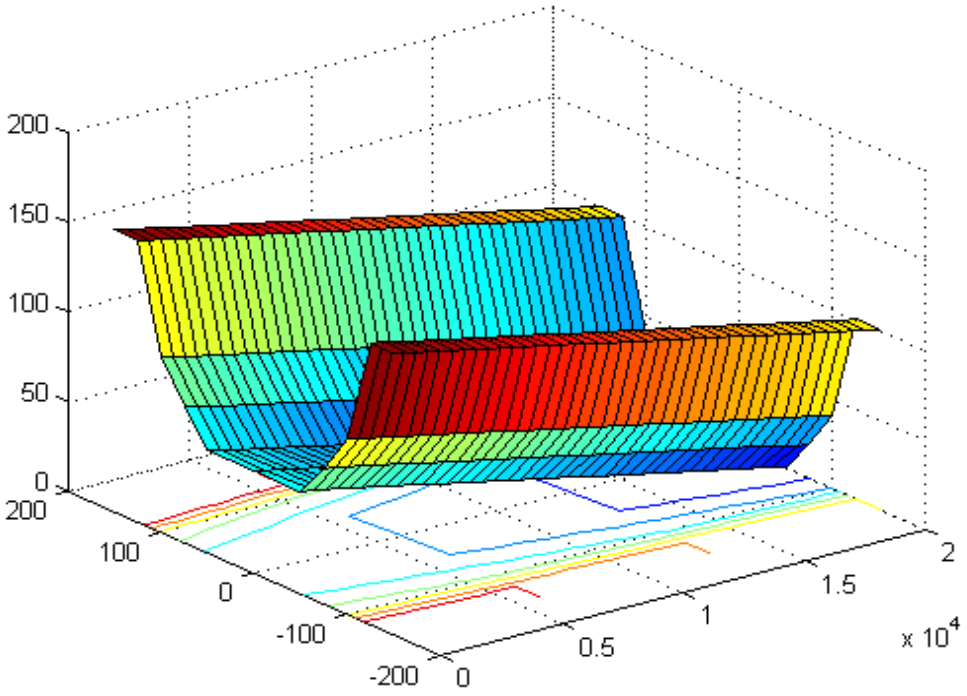


圖 65 60 分鐘後底床高程（圓弧崩坍機制）

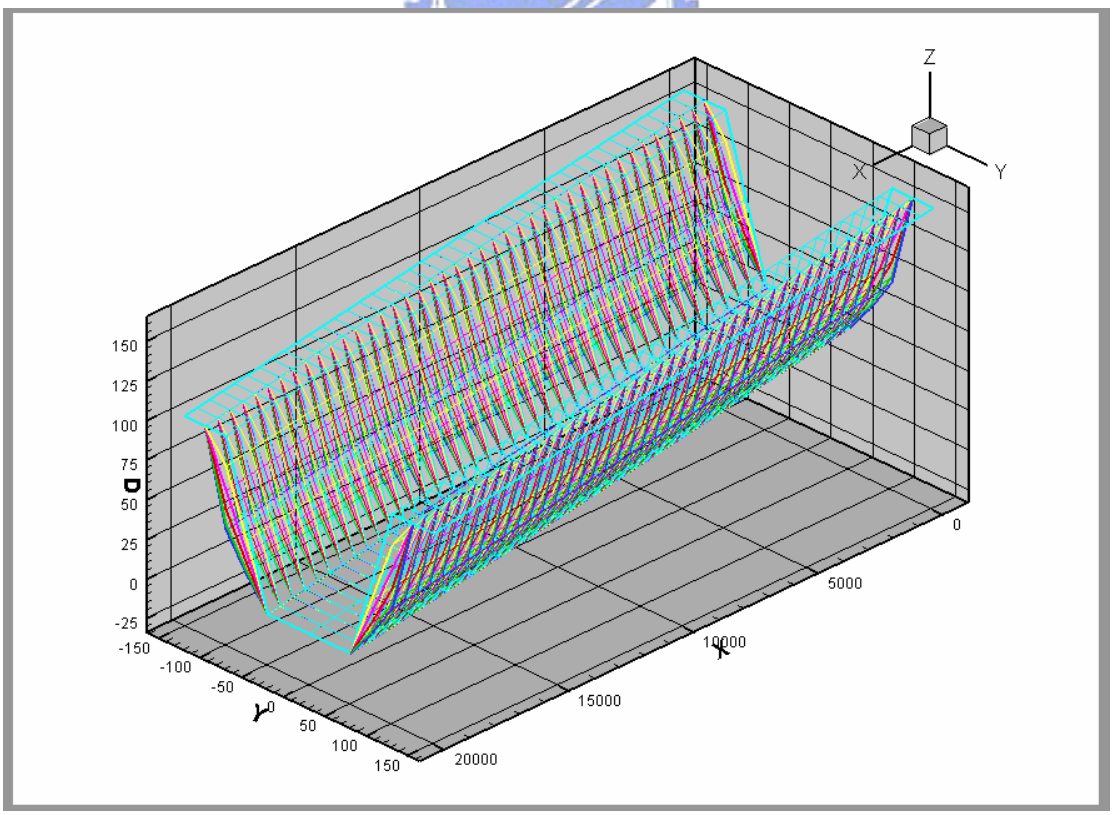


圖 66 底床高程變化情形（圓弧崩坍機制）

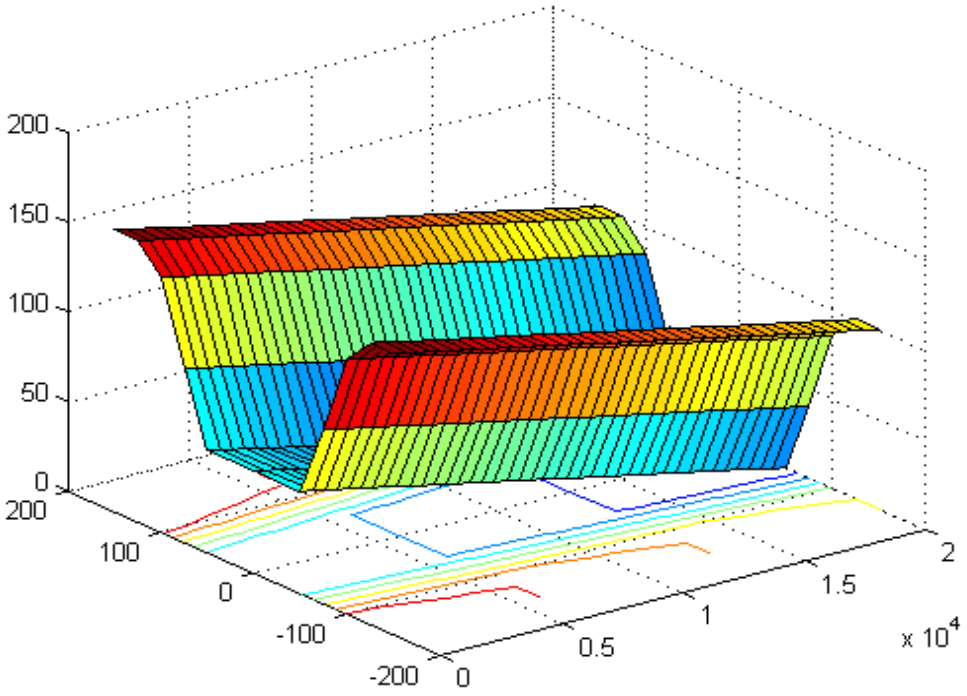


圖 67 10 分鐘後底床高程（平面崩坍機制）

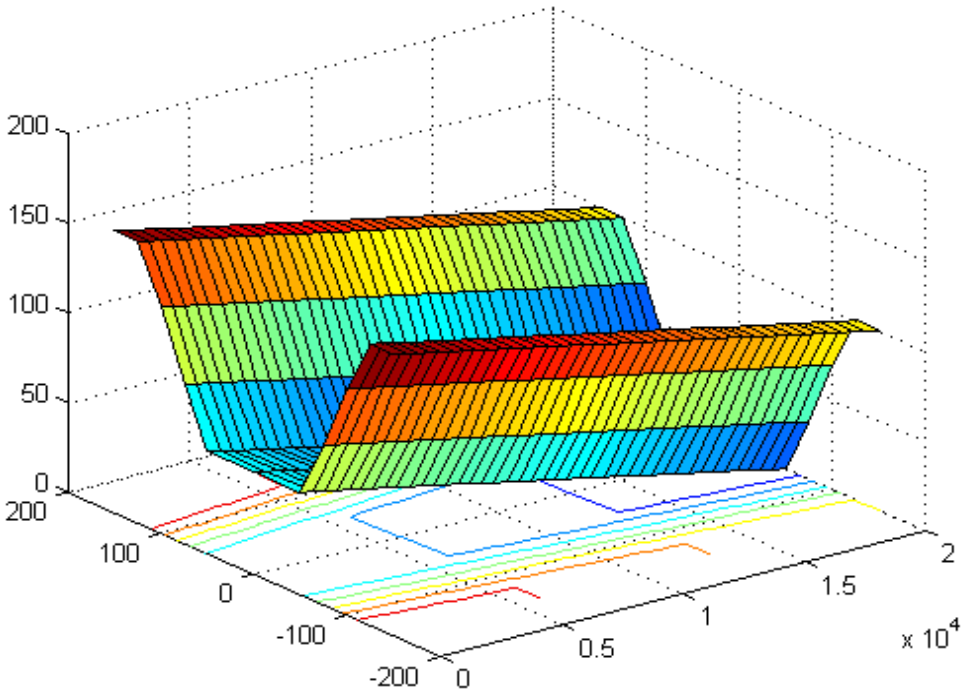


圖 68 20 分鐘後底床高程（平面崩坍機制）